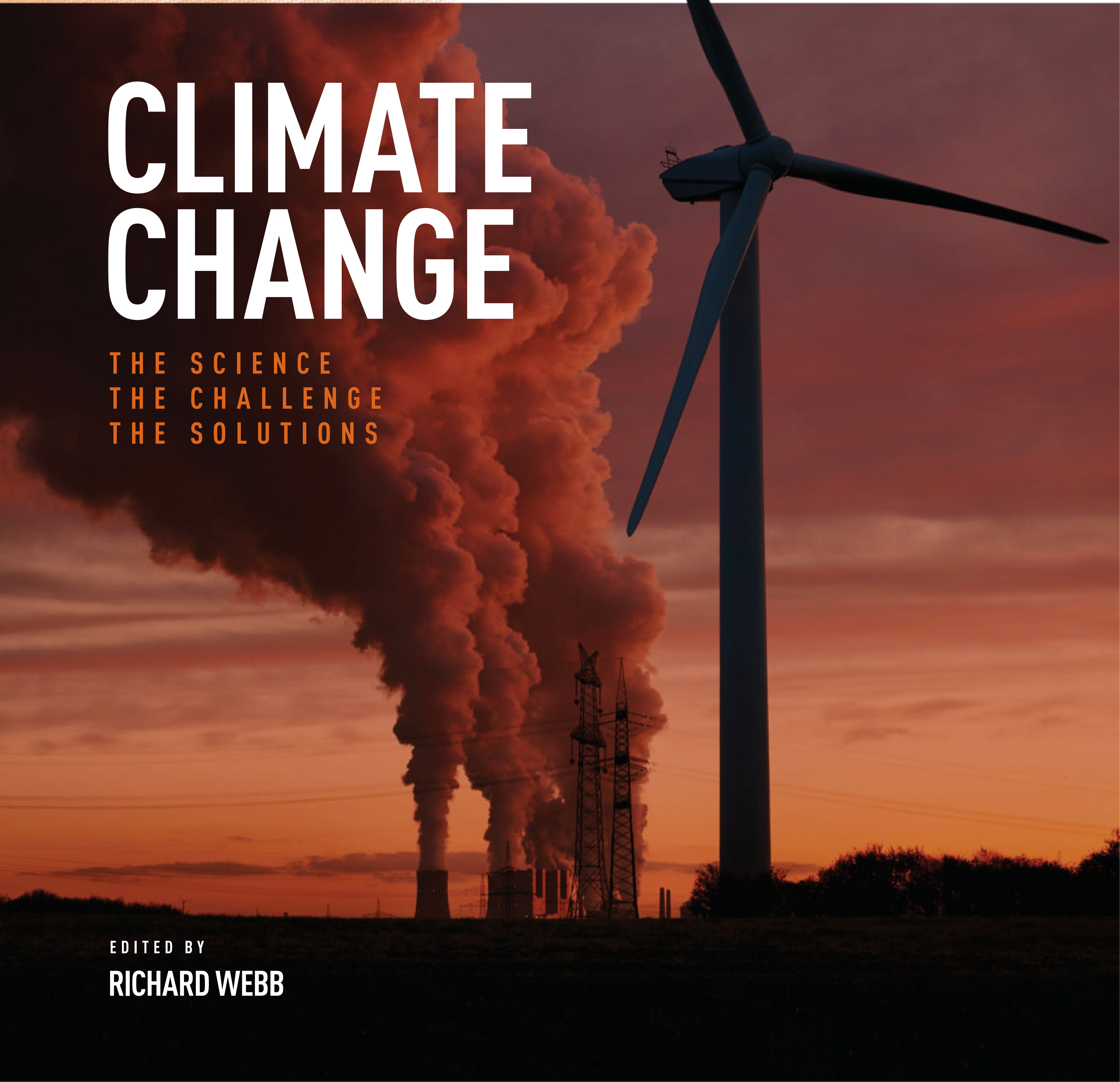
New Scientist

# ESSENTIAL GUIDE Nº8

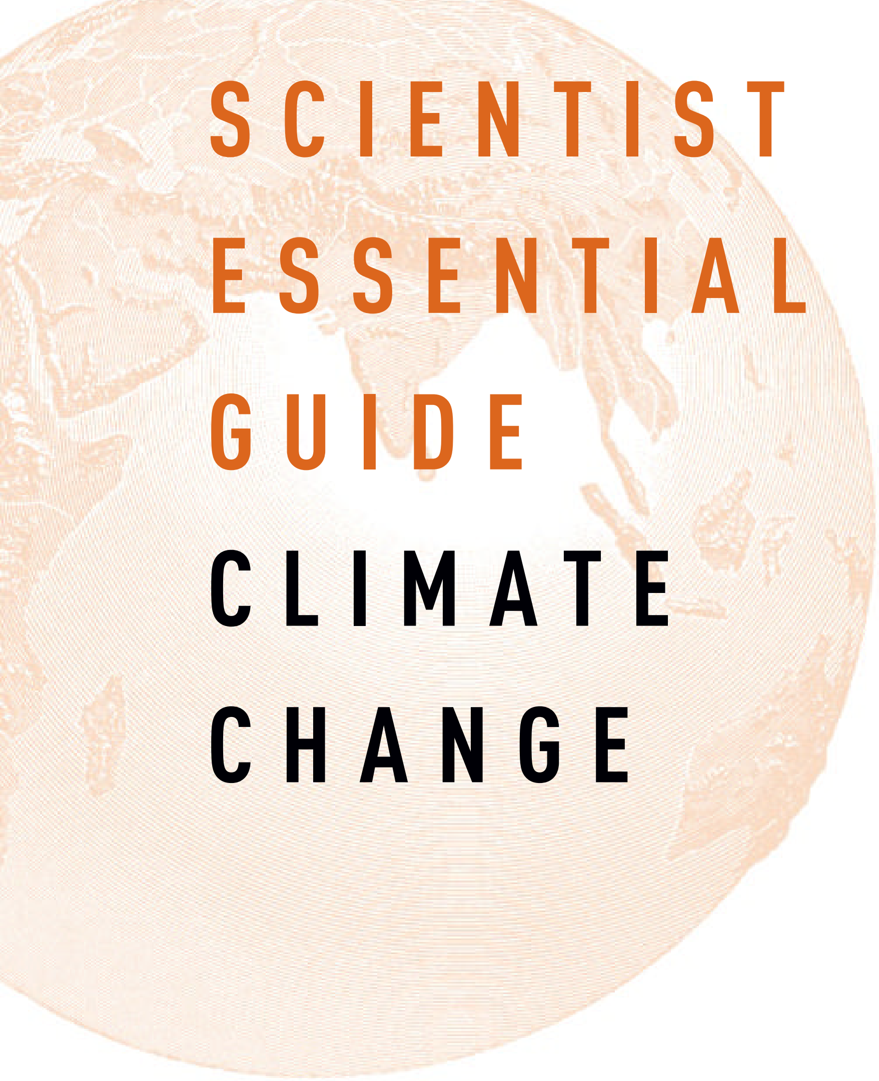
WHAT'S DRIVING IT
THE IMPACTS WE'RE SEEING
HOW BAD IT COULD GET
THE ACTION WE NEED
WHAT WE CAN ALL DO
*AND MORE*



# CLIMATE CHANGE

THE SCIENCE
THE CHALLENGE
THE SOLUTIONS

EDITED BY
RICHARD WEBB



# NEW SCIENTIST ESSENTIAL GUIDE
# CLIMATE CHANGE

CLIMATE CHANGE is the greatest challenge of our age – perhaps of any age, measured by the size of societal change needed to mitigate it and adapt to it.

We stand now at a critical juncture. As this latest *New Scientist Essential Guide* is published, an intense diplomatic effort is under way ahead of the crucial UN-backed COP26 climate summit in Glasgow, UK, in November 2021. At stake is a credible plan to deliver the goal agreed in Paris in 2015, to limit global warming to a nominally safe 1.5°C by reducing greenhouse gas emissions to "net zero" by mid-century.

There is no better time to be informed about what's at stake – about the basic science of climate change, the history of efforts to combat it, the effects of global warming that we are already seeing, and the technologies and innovations that will help us bend the climate curve, now and in the future.

I hope you find it an informative and stimulating read, one that will also perhaps help energise you to play the part all of us can have in meeting the climate challenge. Feedback is, as ever, welcome at essentialguides@newscientist.com. *Richard Webb*

NEW SCIENTIST ESSENTIAL GUIDES
NORTHCLIFFE HOUSE, 2 DERRY STREET,
LONDON W8 5TT
+44 (0)20 7611 1200
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**EDITOR** Richard Webb
**DESIGN** Craig Mackie
**SUBEDITOR** Chris Simms
**PRODUCTION AND APP** Joanne Keogh
**TECHNICAL DEVELOPMENT (APP)**
Amardeep Sian
**PUBLISHER** Nina Wright
**EDITOR-IN-CHIEF** Emily Wilson
**DISPLAY ADVERTISING** +44 (0)20 7611 1291
displayads@newscientist.com

**ABOUT THE EDITOR**
Richard Webb is executive editor of *New Scientist*

**ADDITIONAL CONTRIBUTORS**
Michael Brooks, Julia Brown, Peter Fairley, Linda Geddes,
Rowan Hooper, Graham Lawton, Michael Le Page, John Pickrell,
Kate Ravilious, Michael Slezak, Adam Vaughan

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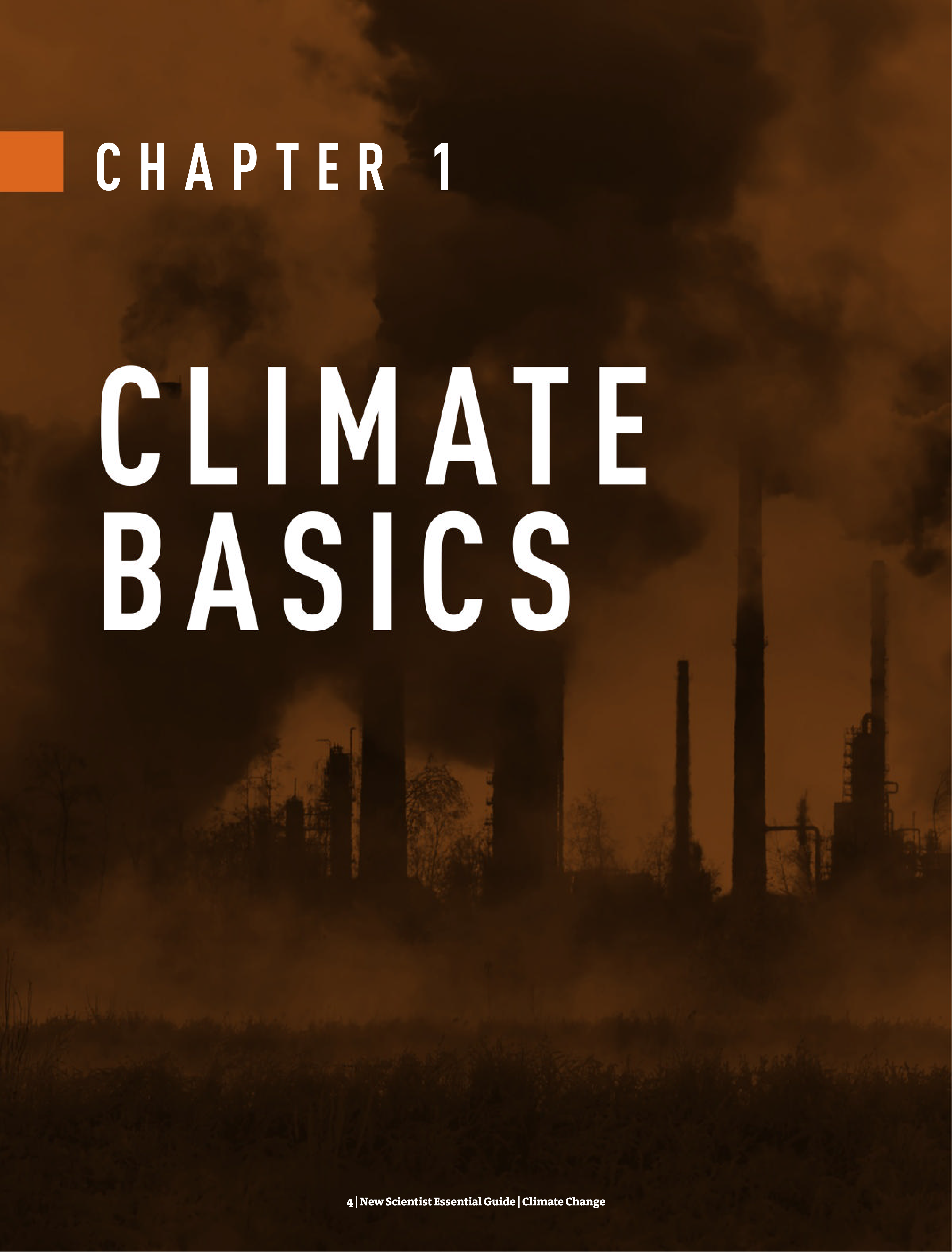
## CHAPTER 1

# CLIMATE BASICS



The details might be complex, but there's no great mystery as to why our planet's climate is changing.

**We can trace how cyclical variations in the concentration of greenhouse gases such as carbon dioxide have caused Earth's temperature to rise and fall in its past. What is different now is the intervention of a new and uniquely powerful force – us.**

# WHAT IS CAUSING CLIMATE CHANGE?

**The planet is warming, and we are warming it. That conclusion is the central fact of the story of climate change. At its heart is nothing more than basic physics – and changes in how humanity is exploiting Earth's resources.**

RIGHT: PANKSVATOUNY/ISTOCK
PREVIOUS PAGE: HRAMOVNIC/ISTOCK

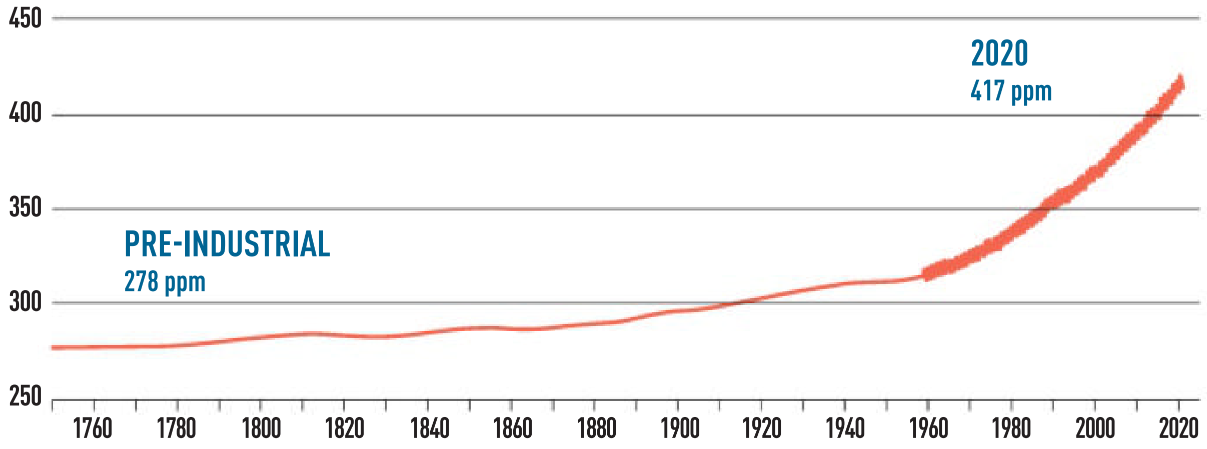
IT MAKES up just 0.04 per cent of the atmosphere, but carbon dioxide is a small molecule with a big bite. We have known this for more than 150 years. In 1861, John Tyndall discovered that $CO_2$'s three atoms vibrate when hit by certain photons. Photons from the sun pass straight through the atmosphere, unhindered by $CO_2$, but when they reach Earth's surface they bounce back as infrared photons – or heat, in other words.

Instead of passing through the atmosphere, these photons are absorbed by $CO_2$ and released again, only this time they fly off in random directions. More heat stays within the atmosphere than goes back out into space: the greenhouse effect.

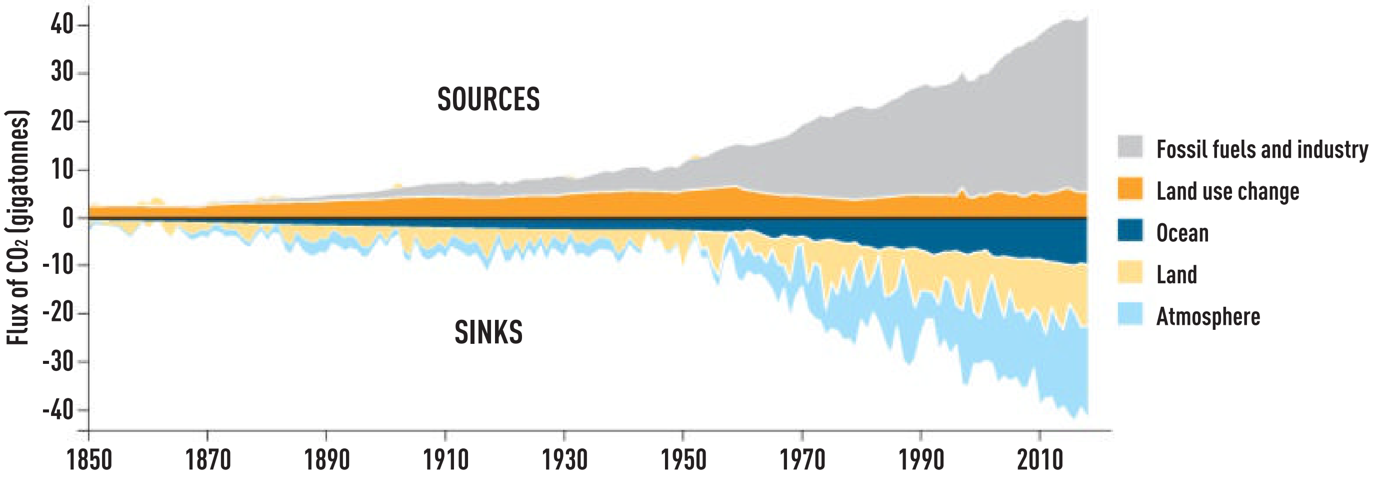
Other greenhouse gases act in the same way: methane, nitrous oxide, CFCs, ozone and water. But $CO_2$ is the big one. Some is taken up by plants and returned to the soil, some is absorbed by the oceans, and some is stored in rocks that react with $CO_2$ when exposed to air. It can stay in the atmosphere for thousands of years, so each additional molecule thickens Earth's warming blanket permanently.

In March 1958, climate scientist Charles David Keeling began measuring atmospheric carbon ›

Atmospheric carbon dioxide is now 50 per cent above pre-industrial levels. Besides emissions from burning fossil fuels, land use change as more areas become deforested is a significant source of greenhouse gases



SOURCE: ICE CORE DATA FROM MACFARLING ET AL. (2006), MAUNA LOA DATA (1958-) FROM THE SCRIPPS $CO_2$ PROGRAM, 2021 FORECAST FROM UK MET OFFICE



SOURCE: FRIEDLINGSTEIN ET AL., EARTH SYSTEM SCIENCE DATA, DOI.ORG/GGD7P4

dioxide levels from a monitoring station atop Mauna Loa in Hawaii. The readings continue to this day, now carried out by the US National Oceanic and Atmospheric Administration (NOAA). Together with measurements of air trapped in ice cores collected from the Antarctic and elsewhere, our record of the concentrations of this crucial greenhouse gas stretches back 800,000 years.

These records show a historically unparalleled rise in atmospheric $CO_2$, beginning in the late 18th century. This was when the first industrialising countries in the West started mining and burning coal in large quantities. Coal, being mainly carbon from fossilised organic matter laid down hundreds of million years ago, creates $CO_2$ when burned in oxygen-containing air.

In the 20th century, ballooning population and consumption vastly increased the quantity of fossil fuels – coal, but also oil and gas – being extracted and burned to produce electricity, propel vehicles, heat homes and power industrial processes. Adding to that, humans claiming ever more land for crops and livestock has destroyed or degraded many ecosystems, chief among them tropical rainforests, that act as sinks for greenhouse gases. The combined result is skyrocketing levels of not just $CO_2$, but also methane and nitrous oxide, released largely through agricultural activities and land use change (see diagram).

From a pre-industrial level of around 280 parts per million, in April 2021 the average atmospheric $CO_2$ concentration at Mauna Loa hit 419 parts ppm – higher than at any point in the past 800,000 years. Climate change, rather than global warming, is now for many people the preferred term for the result, because the warming caused by excess greenhouse gases leads to many other climatic changes such as more intense rainfall. In practice, however, both terms are used interchangeably. ▮

# HOW MUCH HAS THE PLANET WARMED?

**As part of the Paris climate accord of December 2015, nearly every country in the world agreed to try to limit the global average temperature increase to 1.5°C above pre-industrial levels. To do that, we must first know how much our emissions have heated the planet already. The uncertainties start there.**

All but one of the 10 hottest years on record have been in the 21st century, most in the past decade. (Excess temperature over the 1901-2000 average, rolling average September-August)

| | |
|---|---|
| 2015-2016 | 1.06°C |
| 2019-2020 | 1.01°C |
| 2018-2019 | 0.91°C |
| 2016-2017 | 0.91°C |
| 2014-2015 | 0.84°C |
| 2017-2018 | 0.82°C |
| 2009-2010 | 0.75°C |
| 2013-2014 | 0.73°C |
| 1997-1998 | 0.69°C |
| 2006-2007 | 0.67°C |

SOURCE: NOAA

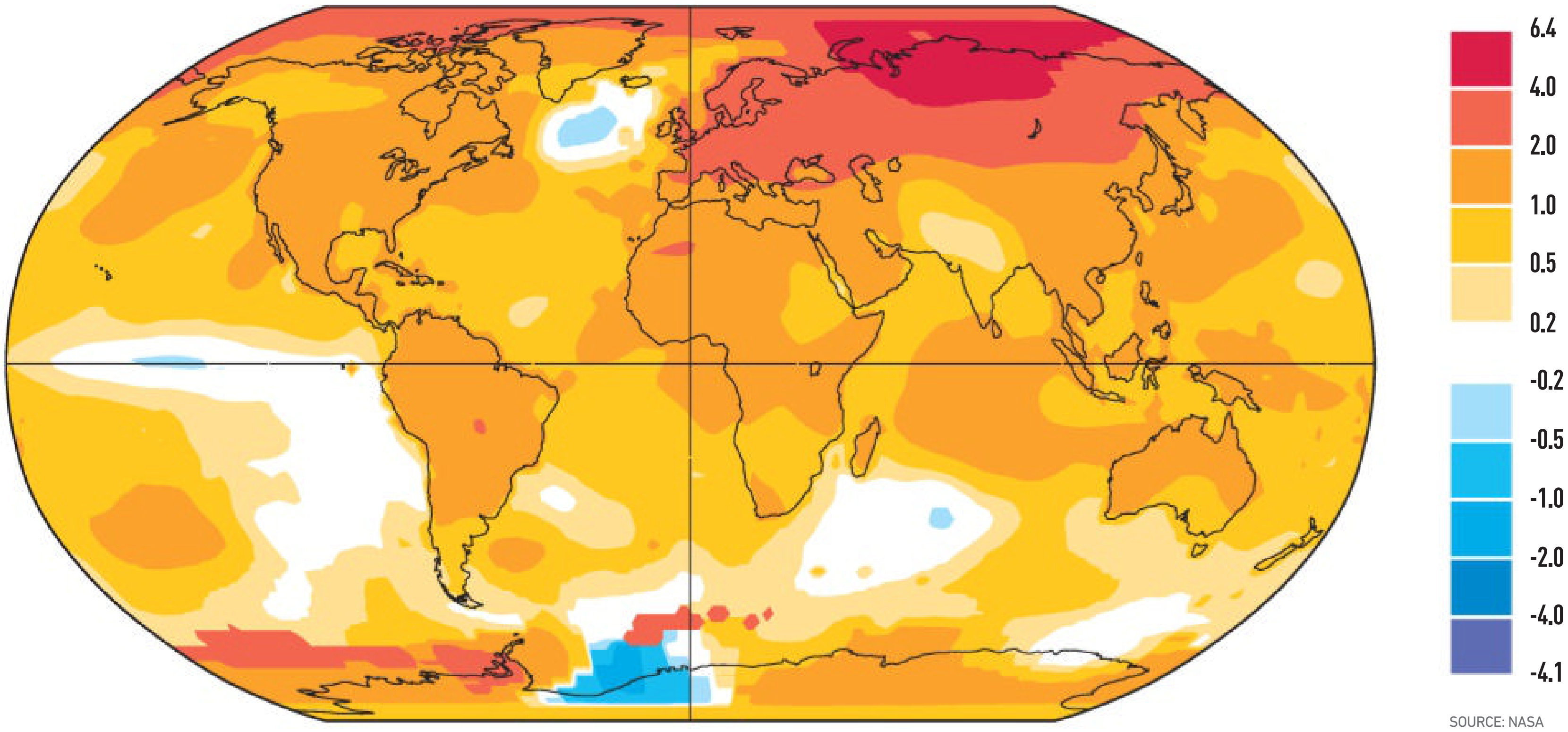
→ Turn to chapter 2 for more on efforts to curb global warming to 1.5°C

THE best way to measure global warming would be to look at Earth as a whole: land, sea and atmosphere. But our measurements focus on the thin layer we live in. Mean global surface temperature usually refers to the heat of the air 2 metres above the land surface, or at the sea's surface.

We get an idea of how this temperature is changing from thousands of weather stations on land, and from ships and buoys at sea. Each reading is checked to see whether the temperature is lower or higher than the long-term average for that place at that time of year. They are then combined to work out how the average global surface temperature is changing relative to the long-term average, or baseline.

This isn't simple. To name just one problem, you can't have fixed weather stations in an ocean full of shifting ice, so we have few measurements from the Arctic. The HadCRUT temperature record, maintained by the UK's Met Office, simply leaves the Arctic out. NASA's GISTEMP record estimates Arctic temperatures based on surrounding stations. Because the Arctic is heating rapidly, NASA's figures suggest there has been nearly 0.1°C more warming across the planet than the Met Office's do. Other climate institutions, among them the World Meteorological Organization ›

The map of the variation in 2020 global average temperature (in °C) compared with the 1951-1980 baseline shows most areas of the planet were significantly warmer, especially at northerly latitudes



SOURCE: NASA

(WMO), the EU-funded Copernicus Climate Change Service (C3S) and the US National Oceanic and Atmospheric Administration (NOAA), have their own slightly differing methodologies.

Further confusion surrounds the baseline question. Global temperature records go back no further than 1850, but the industrial age began a century earlier. Computer models suggest the world was already up to 0.2°C warmer before 1850. If you use the Met Office record and take 1850 to 1900 as the baseline, there has been around 0.9°C of warming so far. Go with NASA and the earlier, pre-industrial baseline, and there has been 1.2°C. NOAA, which uses the average temperature during the 20th century as its baseline, comes in somewhere in between.

All the records agree on the trend, however. According to NOAA, 2020 was the second warmest year on record worldwide, knocking 2019 into third place. The average land and sea temperature was 1.01°C above the 1901-2000 baseline figure in the 12 months to August 2020, second only to a 1.06°C excess recorded ending in August 2016 (see table, page 9). The land surface temperature for 2020 was 1.59°C, exceeding the record set in 2016 during an El Niño, a phase in which warm waters spread across the Pacific and temporarily boost the global surface temperature. Copernicus and NASA have 2020 tying with 2016 as the warmest year on record. Analyses from the WMO and the Met Office ranked 2020 among the top-three warmest years on record.

On current trends, the first year to exceed 1.5°C above the 1850 to 1900 average will probably occur within the 2020s. As climate is weather averaged over many years, it would be premature to regard this as passing the limit. The threshold is likely to be crossed during an El Niño. Temperatures will drop a little again when this passes.

A reasonable definition is that we will go over the limit when the average, long-term temperature rise exceeds 1.5°C. It is on track to do that between 2026 and 2042, and to exceed 2°C above its pre-industrial level between the 2040s and 2070s. Those dates are sufficiently close that almost all schemes for reducing greenhouse gas emissions to limit warming to 1.5°C involve exceeding that temperature rise in the middle part of the century and dialling it back down by 2100, through sucking $CO_2$ back out of the atmosphere. That raises a big question of how: at present, we have lots of ways of capturing greenhouse gases on a small scale, but no technology that works on the stupendous scale required to reverse decades of fossil fuel burning. ▮

→ See page 58 for more on routes to 1.5°C warming

# HOW BAD COULD IT GET?

PIYASET/ISTOCK

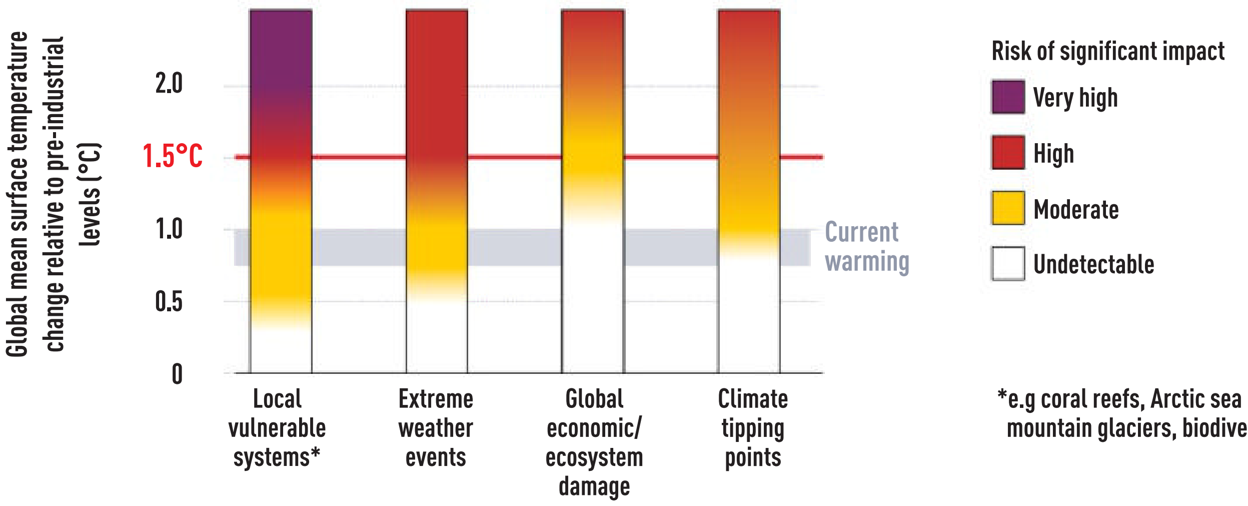
**The world has made some progress in cutting greenhouse gas emissions, but not nearly enough. Meanwhile emerging research on "climate sensitivity" suggests that the impact of the emissions we are pumping into the atmosphere could be even greater than we feared.**

THE fate of much life on the planet depends on three main factors. First, how much more carbon dioxide we add to the atmosphere. Second, how the planet changes in response to all that extra $CO_2$: how much it will warm the planet, and its impact on sea level rise and extreme weather. Third, how well we prepare for the coming changes.

Of these factors, our $CO_2$ emissions are by far the most important. They are causing climate change and they are within our control. In 1988, NASA climate scientist James Hansen gave the first high-profile warning that we needed to cut emissions. Decades of denial followed, but today that argument is largely won. "Everybody seems to realise that climate change is something that needs to be taken seriously," says Lisa Schipper at the Environmental Change Institute at the University of Oxford. "People are enraged and engaged."

Such a plan is desperately needed. Carbon dioxide emissions are still rising, as they have more or less continuously from under 40 million tonnes of $CO_2$ per day in 1970 to more than 100 $MtCO_2$ today. There have been some declines when the global economy has faltered, such as after the 2007-08 financial crisis, but emissions growth has always resumed when the ›

As global temperatures rise, so does the risk of both general impacts (below) and specific impacts (right)



*e.g coral reefs, Arctic sea ice, mountain glaciers, biodiversity hotspots

economy picked up. The coronavirus pandemic produced by far the biggest fall in emissions yet seen, with overall levels down by between 4 and 7 per cent. Yet this was short-lived. Emissions had bounced back to near pre-pandemic levels by around September 2020. At the current rate, a doubling of atmospheric $CO_2$ levels from pre-industrial times will probably happen sometime between 2070 and 2080.

→ See page 30 for more on climate change and the pandemic

It could be worse. Emissions would be growing even faster now if nothing at all had been done. Many countries have managed to cut their overall emissions, typically by using less coal and more renewables to generate electricity. We aren't heading for the worst-case scenario, called RCP8.5, that climate researchers have been considering. That could have led to around 5°C of warming by 2100. "We are in a better position than expected five or 10 years ago, but we are still taking baby steps," says Glen Peters at the Center for International Climate Research in Norway.

According to the independent Climate Action Tracker, we are heading for warming of between 2.7°C and 3.1°C by 2100. If countries meet all existing pledges and targets, it would be around 2.6°C. And if all nations considering net-zero targets actually met them, warming could be limited to 2.1°C by the end of the century.

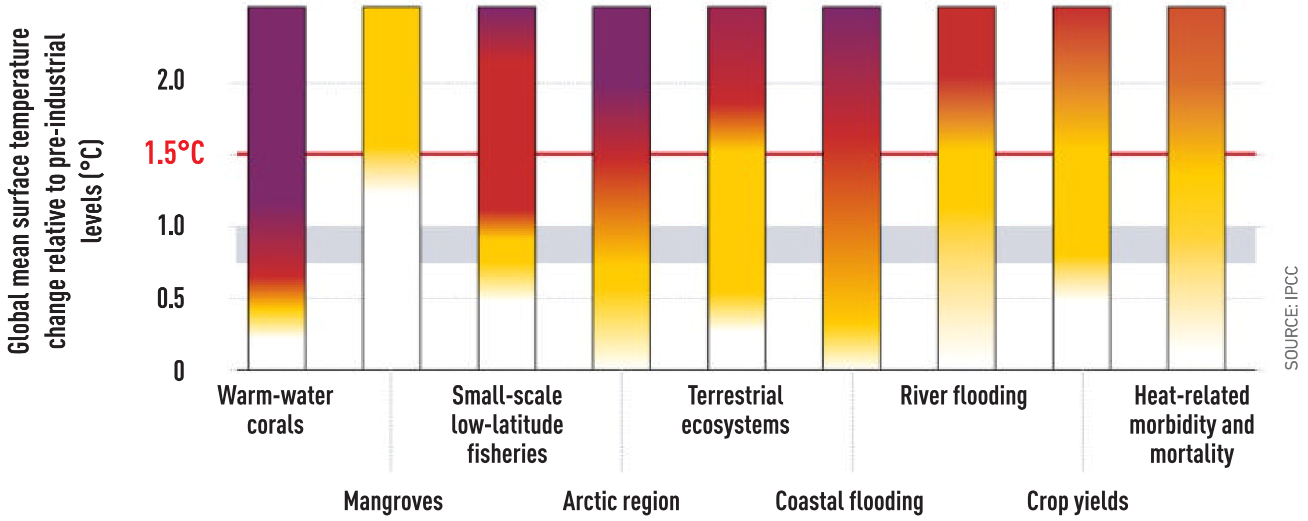
This suggests we are within sight of the 2°C target, which is very encouraging. However, even countries committed to a net-zero target will find it immensely challenging. The UK has cut emissions faster than most other large economies, for instance, but its climate watchdog has repeatedly warned that it isn't on track to meet its long-term targets. While the UK has transformed its electricity generation system – the relatively easy part – it has done little to tackle emissions from trickier sources such as transport, heating and farming. Significantly reducing those will need new policies, as well as lifestyle changes. That picture is broadly similar in many rich countries.

→ Turn to page 64 for solutions to reduce emissions

The longer emissions keep increasing, the bigger the cuts that will be required to limit warming to under 2°C, let alone 1.5°C. Achieving this now already requires drastic action: we need emissions reductions of the size caused by the coronavirus pandemic to happen every year, says Peters, but without any rebound.

That might be an underestimate when we bring into play the second crucial factor: how much all the extra $CO_2$ we are pumping into the atmosphere will actually warm the planet. And here the latest news is largely bad. "The science, if anything, has become more pessimistic," says Stefan Rahmstorf, a climate scientist at the University of Potsdam, Germany. "The signs from the science are pointing towards more urgent climate action being needed."

The amount greenhouse gases warm the planet depends on a vast array of feedback effects. Some are relatively simple: for instance, warming increases the amount of water vapour in the atmosphere, a potent



SOURCE: IPCC

greenhouse gas. Others are extremely complex and poorly understood. Clouds, for example, can have both warming and cooling effects depending on their location, height and thickness.

Some feedbacks, such as increases in water vapour, kick in quickly. Others, such as the melting of ice sheets, take centuries or millennia. How much warming these feedbacks cause is known as climate sensitivity. If climate sensitivity is low, we have a chance of limiting warming to under 2°C, even if we don't quite get to net zero by mid-century. If it is high, warming could exceed 2°C even if we meet that target.

When climate scientists talk about climate sensitivity, they usually mean how much warming would occur with a doubling of $CO_2$ levels, as is possible by 2070. There are three main ways to work out this "equilibrium" climate sensitivity: looking at how the climate has changed in the distant past, examining changes over the past centuries, and using computers to model key short-term feedbacks. These methods give a wide range of answers. A 2013 report by the Intergovernmental Panel on Climate Change (IPCC), the UN-led body that summarises the scientific evidence, said it could be anywhere from 1.5°C to 4.5°C, the same as the first estimate in 1979 made by Hansen and his colleagues.

Recent studies suggest that climate sensitivity is towards the upper end of this range. One line of evidence comes from the latest generation of climate models, whose results will help inform the next set of IPCC reports, due to be published in 2021 and 2022. Newer models generally simulate things such as clouds more accurately than previous models, and many show higher sensitivity. According to the UK Met Office's model, sensitivity is a whopping 5.5°C. Many climate scientists think such high sensitivities are unlikely, but they aren't ruling them out. "We can't say they are wrong," says Richard Betts at the Met Office Hadley Centre. "Unlikely things do happen sometimes."

In 2020, a major study concluded that equilibrium climate sensitivity is between 2.4°C and 4.6°C. "Their most confident conclusion was that we could rule out the low sensitivity, which is not good," says Betts. "They also concluded with less confidence that the higher sensitivities are less likely, which is good news to some extent."

But even the improved models don't tell the whole story. Half the $CO_2$ we emit is soaked up by the land and seas, for instance as vegetation grows. As the planet gets warmer, plants on land aren't going to take up ever more $CO_2$. According to one study, the Amazon rainforest is already releasing more greenhouse gases than it absorbs, due to the combined effect of deforestation and climate change. Increasing amounts of carbon will also be released as Arctic permafrost thaws. Carbon dioxide is less soluble in warm water, so warming oceans may soak up less of it, too.

Technically, these are just more feedbacks that help determine sensitivity, but most climate models don't model carbon-cycle feedbacks, because it involves adding many extra processes and requires more computing power. Instead, these models use best estimates of carbon-cycle feedbacks made by other teams.

In 2020, Betts and Zeke Hausfather at the Breakthrough Institute in California concluded the range of uncertainty on these estimates mean there might be anything from 10 per cent less warming to ›

# CLIMATE MODELS AND UNCERTAINTY

You cannot predict the exact path a ball will take as it bounces through a pinball machine. But you can predict that the average score will change if the entire machine is tilted. Similarly, while we cannot predict the weather in a particular place and on a particular day in 100 years' time, we can be sure that on average it will be far warmer if greenhouse gases continue to rise.

While weather and to some extent climate are chaotic systems, that does not mean that either are entirely unpredictable. The unpredictable character of chaotic systems arises from their sensitivity to any change in the conditions that control their development. What we call the weather is a highly detailed mix of events that happen in a particular locality on any particular day – rainfall, temperature, humidity and so on – and its development can vary wildly with small changes in a few of these variables.

Climate, however, is the bigger picture of a region's weather: the average, over 30 years (according to the World Meteorological Organizations's definition), of the weather pattern in a region. While weather changes fast on human timescales, climate changes fairly slowly. Getting reasonably accurate predictions is a matter of choosing the right timescale: days in the case of weather, decades in the case of climate.

Climate scientists sometimes refer to the effects of chaos as intrinsic or unforced variability: the unpredictable changes that arise from the dynamic interactions between the oceans and atmosphere rather than being a result of "forcings" such as changes in solar irradiance or greenhouse gases.

The crucial point is that unforced variability occurs within a relatively narrow range. It is constrained by the major factors influencing climate: it might make some winters bit a warmer, for instance, but it cannot make winters warmer than summers.

Put the other way round, two or three warmer winters in a row could be due to unforced variability rather than global warming, just as two or three high scores in pinball do not necessarily mean the table is tilted. But the more warmer winters there are, or more high scores there are on a certain pinball machine, the less likely it is to be due to the chaos inherent in the system.

The uncertainties in climate prediction are even greater than in weather prediction

The best supercomputer climate models available today simulate the intricate and non-linear interplay of solar radiation, atmospheric dynamics, geography, geology, ocean circulation, ice and the biosphere that forms the Earth system in fine-grained detail. Climate scientists then toggle various parameters, such as adding loads of carbon dioxide, to predict what might happen.

To account for the influence of chaos, these models are run repeatedly, with slightly different starting conditions. The difference in outcomes gives an indication of the uncertainty in any given prediction, of the range of possible outcomes. The results, as summarised in the periodic Assessment Reports produced by the Intergovernmental Panel on Climate Change show that, though we can't be certain where the climate ball will land, we are as certain as we can be that the table is tilted.

PETES PHOTOGRAPHY/ISTOCK

25 per cent more warming than projected by models. "This means that we cannot fully rule out a small chance of close to 5°C warming in a current-policy world where our best estimate is 3°C, or close to 4°C warming in a pledges-targets world where our best estimate is 2.5°C," says Hausfather.

The picture is also grimmer when it comes to the impacts of warming. Take sea level. This has already risen 0.3 metres since the industrial age began, and the process is accelerating. According to a 2019 IPCC report, sea level could rise between another 0.3 and 1.1 metres by 2100 depending on how much the planet warms.

This is much higher than earlier IPCC estimates, but may still be on the low side if, as studies increasingly suggest, the great ice sheets covering Greenland and Antarctica disintegrate much faster than we thought. "The IPCC is still a conservative voice," says Rahmstorf. "The more advanced the ice sheet models are becoming, the more risky it looks." Some researchers think the rise could be more than 2 metres by 2100. The IPCC estimate is for as much as 5 metres by 2300. Some scientists think we could see 8 metres by 2200.

Then there is the impact that global warming is having on the weather, with ever more extreme events, from wildfires to storms to flooding, occurring around the world. 2020 saw unprecedented fires in Australia and floods costing China at least $26 billion, to mention just two. The evidence that climate change is to blame is growing ever stronger.

→
Chapter 3 has more on detail on climate impacts from polar melting to extreme weather

Many major impacts of warming are now unavoidable to some extent. "Realistically, the kind of changes we are going to be facing are pretty horrid," says Schipper. She doesn't think we will be able to limit warming to 1.5°C, although she thinks 2°C is still doable.

That brings us to the third factor that will determine how badly climate change affects us: how well we adapt to it. "Because we haven't been able to mitigate greenhouse gas emissions properly, we now really have to look at adaptation," says Schipper.

Some countries are doing just that. For instance, with Jakarta slowly sinking, Indonesia has announced plans to create a new city to become its capital. Unfortunately, a review by Schipper and her colleagues has found that, all too often, adaptation projects end up making matters worse. "It can backfire and make people more vulnerable," says Schipper.

In parts of the world, the building of sea walls and levees has encouraged more development in vulnerable areas, leading to bigger disasters when those defences are breached. Similarly, irrigation measures intended to help farmers cope with shifting climates have led to them carrying on growing the same crops when they really need to switch to something more suitable to the changing conditions. "It delays your actual response, your adaptation," says Schipper.

So the future remains very much undecided. With swift and drastic action, and a bit of good fortune, we might still limit warming to around 2°C. But if we do too little, too late, and climate sensitivity and carbon-cycle feedbacks are on the high side, many children alive today might live to see 5°C of warming or more. Whether modern civilisation would survive in such a world, no one can say. ■

# EARTH'S CLIMATE PAST

**Our planet's climate has varied naturally over geological time. Piecing together the record brings some good news: the biosphere has endured some very hot periods and lived to tell the tale. The bad news is that the next hothouse may be more extreme than anything Earth has experienced before. In that case, it really is goodbye, cool world.**

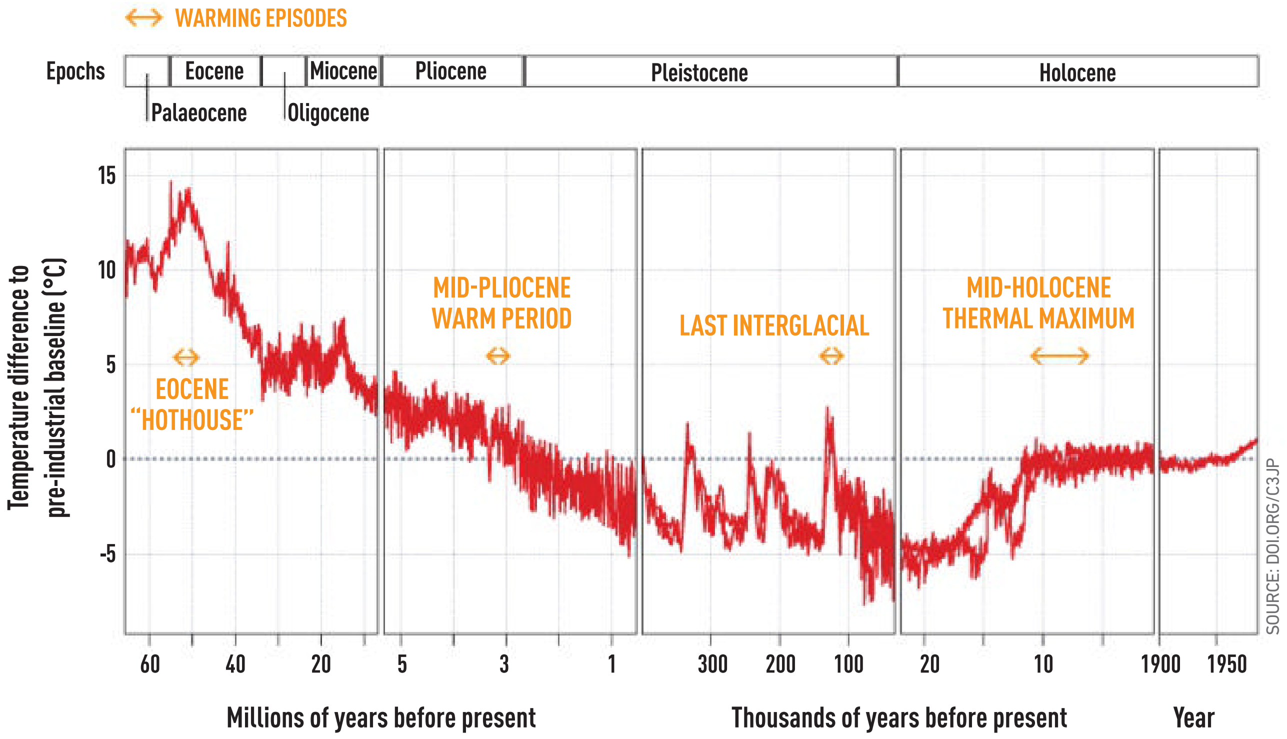
WELCOME to Icehouse Earth. It may not feel like it but, right now, our planet is in an ice age. It started about 2.6 million years ago and, until recently, showed little sign of letting up. In the 1970s, scientists were even worried that we were about to plunge into another full-blown icy spell.

Today, those fears have evaporated into a fog of greenhouse gases – but what will happen in the centuries to come? The standard approach to finding out, using powerful supercomputer climate models, is producing increasingly realistic results, but not if you want to go beyond the next 300 years or so. Going much further into our climate future requires a perhaps unexpected step: delving into Earth's deep climate past.

The earliest inklings that Earth's climate was radically different in the past came in the 1800s, when geologists were stumped by phenomena such as glacial deposits and desert sandstones at temperate latitudes. In the early 20th century, the theory of continental drift appeared to offer an explanation – maybe the deposits had been laid down elsewhere and inched their way to their current positions. But in the absence of accurate temperature records, nobody could be entirely sure.

"Reliable temperature records only go back a couple

Various episodes of warming in past epochs may hold clues to how dramatically Earth's climate will change as it warms now



SOURCE: DOI.ORG/C3JP

of hundred years, so we have to find proxies," says Tracy Aze, a marine micropalaeontologist at the University of Leeds, UK. Proxies are things that are affected by the temperature at the time and that are preserved over very long periods, creating a record of ancient temperatures. "These are typically chemical traces captured in sedimentary rock or ice, which allow us to make inferences about ambient temperatures," says Aze.

Aze analyses the fossilised shells of marine organisms called foraminifera. Oxygen isotope ratios in the calcium carbonate from the shells reveal the temperature of the water in which they formed. Another technique is leaf margin analysis, which gives a proxy for temperatures on land. Put simply, the smoother the edge of a fossil leaf, the warmer the air it grew in. "We try to use as many different lines of evidence as possible," says Aze.

Using such proxies, palaeoclimatologists have painstakingly assembled a reconstruction of Earth's climate stretching back 65 million years, a period that runs from just before a sizzling time known as the Eocene hothouse. Things have, by and large, cooled steadily since then – crucially, with pulses of warming along the way (see diagram, above).

Each past warming period has unique features, so there is no such thing as the perfect analogue for future change. What's more, current global warming is happening way faster than anything Earth has ever mustered of its own accord. The Eocene hothouse, for example, seems to have been caused by pulses of carbon dioxide emitted over thousands of years, not decades as now.

The most recent warming period is the Mid-Holocene Thermal Maximum, which began around 11,000 years ago and lasted 6000 years. This has the advantage of modern physical geography – as you go further back in time, processes such as continental drift and mountain building means Earth looks less and less like today – and ample fossil data, but the average temperature was only about 0.7°C above the pre-industrial baseline. We have already overshot this level, so it isn't an especially illuminating window on the future.

Going further back, the next spike is the last interglacial, around 129,000 to 116,000 years ago. As the name suggests, interglacials are temporary respites within an ice age. The last interglacial is recent enough to pass the physical geography test, but average global temperature was only about 0.8°C above pre-industrial levels. This is enough to rule it out as an analogue, although it does tell us something hugely important. Towards the end of the last interglacial, sea levels had risen by up to 9 metres, inundating wide areas of what today is dry land.

The source of all this water has long been debated, but we now think it was almost certainly the meltwater of a huge ice sheet covering West Antarctica. This has since grown back, but it gives today's climatologists ›

> **“The sea level rise at the end of the last interglacial gives climatologists sleepless nights”**

sleepless nights: its base is below sea level, which exposes it to warming ocean waters and makes it susceptible to sudden melting. That is apparently what happened in the last interglacial, with geological records suggesting that the rate of sea level rise peaked at 2.5 metres per century.

→ Page 40 has more on the threat to today’s polar ice sheets

For the next candidate analogue, you have to go even further back, to a 3-million-year-old episode called the Mid-Pliocene Warm Period. During the Pliocene epoch, gradual cooling from the Eocene was still the dominant direction of travel, but a 300,000-year period significantly bucked that trend. For unknown reasons, $CO_2$ levels in the atmosphere soared and global temperatures followed. This far back, the continents weren’t quite in their modern configuration: North and South America had yet to be joined by the Isthmus of Panama – an event that set in motion the Gulf Stream, an Atlantic Ocean current that plays a crucial role in moving heat around the planet.

→ Turn to page 49 for more on ocean circulation today

Even so, palaeoclimatologists see the Mid-Pliocene as a pretty good analogue of the future Earth. “It’s the first interval which really works,” says Fischer. “$CO_2$ is about the same as today, so that is a direct comparison.” But, he says, even though it was only 3 million years ago, the palaeo figures are a little sparse – there are “only a couple of handfuls of records”.

Nonetheless, we can say with some confidence what the world was like back then. “The global annual mean temperature was between 2°C and 3°C warmer than pre-industrial, with warming more pronounced in higher latitudes,” says Alan Haywood at the University of Leeds, UK. “There was a significant reduction in sea ice in both hemispheres. The Arctic may have been completely free of ice in the summer. The Greenland ice sheet may have retreated to a small ice mass and we believe that the West Antarctic ice sheet was not there. Sea level is somewhere between 15 to 25 metres above modern levels.”

To a large extent, this echoes warnings about where our world is heading. “Yes, you do think, hmmm, I’ve heard this before somewhere…” says Haywood. But the devil is in the detail. Warming at high northern latitudes was around 8°C – much more than our best climate models predict at these $CO_2$ levels. This suggests the models may substantially underestimate how much the Arctic will warm in the long run.

The Pliocene has long been touted as an analogue of the 22nd century and beyond, says Haywood. ›

# CLIMATE CYCLES

Volcanic eruptions are a major natural source of greenhouse gases

PEDRO CARRILHO/ISTOCK

Around 50 million years ago in the early Eocene, 15 million years after the dinosaurs went extinct, Earth was sweltering. Average temperatures were 14°C above pre-industrial levels. There was no permanent ice anywhere on the planet and sea levels were more than 70 metres higher than today.

The cause of this extended heatwave appears to have been a massive injection of greenhouse gases into the atmosphere. The source remains unclear – volcanic eruptions and comet impacts have been proposed – but whatever caused it, carbon dioxide levels peaked at about 1400 parts per million (ppm), compared with around 420 ppm today and 280 ppm in pre-industrial times.

From that high point, Earth gradually cooled, as slow-moving geological processes scrubbed $CO_2$ out of the atmosphere. One key factor was mountain building. New mountains expose silicate rocks, which extract $CO_2$ from the atmosphere as they weather. Around 34 million years ago, it was chilly enough for ice sheets to appear at the South Pole. Another 13 million years on, the North Pole iced up too. The downward trend bottomed out just over 1.2 million years ago. Since then, the globe has warmed a little, but remains firmly in icehouse conditions, with ice caps at both poles.

However, this is far from the whole story. Superimposed on the general cooling trend is a constant and much more rapid oscillation from warm to cold and back again. This is mainly driven by natural fluctuations in Earth's orbit around the sun, which alter the distribution of solar radiation hitting the planet's surface.

The variations are small, but can have big long-term effects. If less sunlight hits northern latitudes, for example, regional temperatures fall and winter snowfall rises. Weaker sunlight also means that the snow survives the summer months, which boosts the reflectivity – or albedo of the surface, bouncing more sunlight back into space and amplifying the cooling. "That's a self-reinforcing effect," says Hubertus Fischer at the University of Bern, Switzerland. "It gets colder, you get more snow, you build up ice masses and that leads to a glaciation."

Cooling induced by orbital variations also causes $CO_2$ levels in the atmosphere to fall. "The greenhouse effect becomes weaker, leading to further cooling," says Fischer. Over tens of thousands of years, this self-reinforcing feedback is enough to flip Earth from warm to cool. But the planet's orbit eventually swings back and the sequence of events reverses.

This process nudges global average temperatures up and down, with a periodicity of around 100,000 years. These are the Milankovitch cycles, named after Serbian astronomer Milutin Milankovitch who proposed them in the 1920s. Occasionally, something else kicks in, turbocharging the process. That may be the confluence of several different orbital eccentricities, or an injection of greenhouse gases. Whatever the cause, Earth experiences unusually strong warming. These are the periods of particular interest to people trying to predict what Earth's climate will be like in the future.

But when he and his colleagues did a formal statistical comparison of climatic similarities between the Pliocene and various computer models of the future, they were in for a shock. Their analysis revealed that under current emissions trajectories "we very quickly arrive at a Pliocene scenario", he says. One model suggests that could happen as early as 2030.

That doesn't mean the imminent loss of ice sheets and huge sea level rises – those will still take centuries to play out – but it does mean that in less than a decade, our climate will have shifted to a state not seen for millions of years.

It isn't all doom and gloom. "Many of the species in the Pliocene are around today, so the fact that we might go back there doesn't necessarily mean we're going to lose a huge number of species," says Haywood. Nevertheless, he acknowledges that the current rate of change might exceed nature's adaptive capabilities. Besides, the Pliocene was essentially a pristine natural ecosystem, which isn't now the case. "We have lost very large areas of natural vegetation and habitat so there are additional stresses that wouldn't have been there in the Pliocene. That's where you get into the realm of ecosystem resilience. I know the biologists are deeply concerned about this," he says.

→
See page 53 for more on climate's impact on biodiversity

And if we don't substantially curb emissions, says Haywood, we soon leave the Pliocene behind and strike out for the Eocene, an extreme hothouse episode when average temperatures were 14°C above pre-industrial and sea levels were more than 70 metres higher. That is a long way off – the Eocene becomes the closest analogue of Earth's climate no sooner than 2150.

But the journey won't be comfortable. "If we stay below 2°C of warming, we can most likely avoid uncontrollable thresholds," says Fischer. "But if we go to 4.5°C or 6°C, we can't say we avoid them." Judging from what happened in the past, he says, that might include catastrophic sea level rise, natural releases of even more greenhouse gases and a sudden collapse of the Gulf Stream. "This will shake our climate system so much we cannot foresee the consequences," he says.

If you think that sounds bad, the palaeoclimatologists still have a joker up their sleeve. "There's a growing realisation that our climate trajectory is taking us into places that are not well understood," says Haywood. "We pretty quickly get into the realms where temperature and precipitation do not match any of our geological references." These hot and saturated "geologically novel climates" don't cover the entire Earth, but by the 23rd century are found across east and South-East Asia, northern Australia and the coastal Americas.

"We see that as a bit of a wake-up call," says Haywood. It took 50 million years for natural processes to undo the warming of the Eocene. We may reverse that in two centuries, with terrible consequences. Call it a lesson from prehistory. ▮

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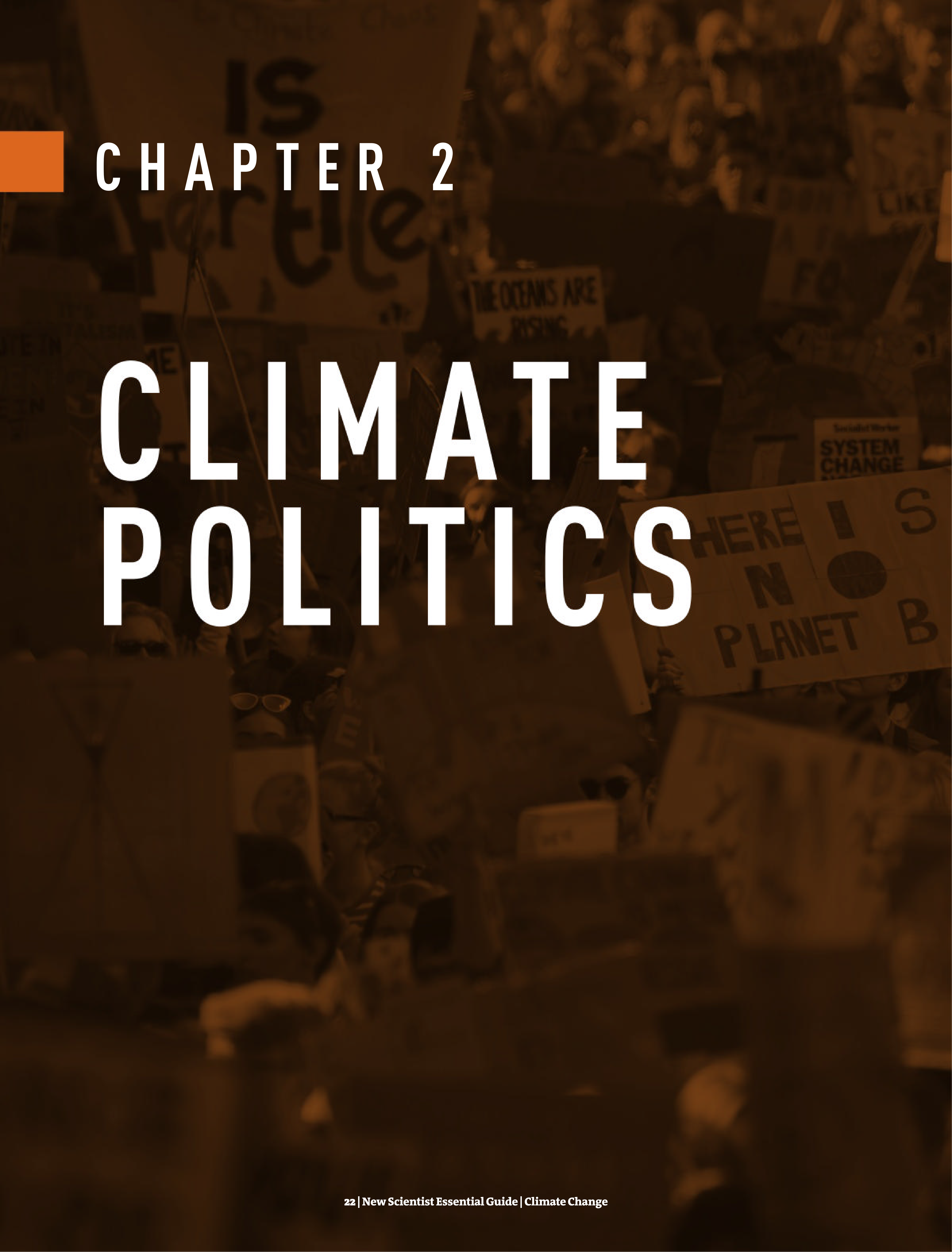
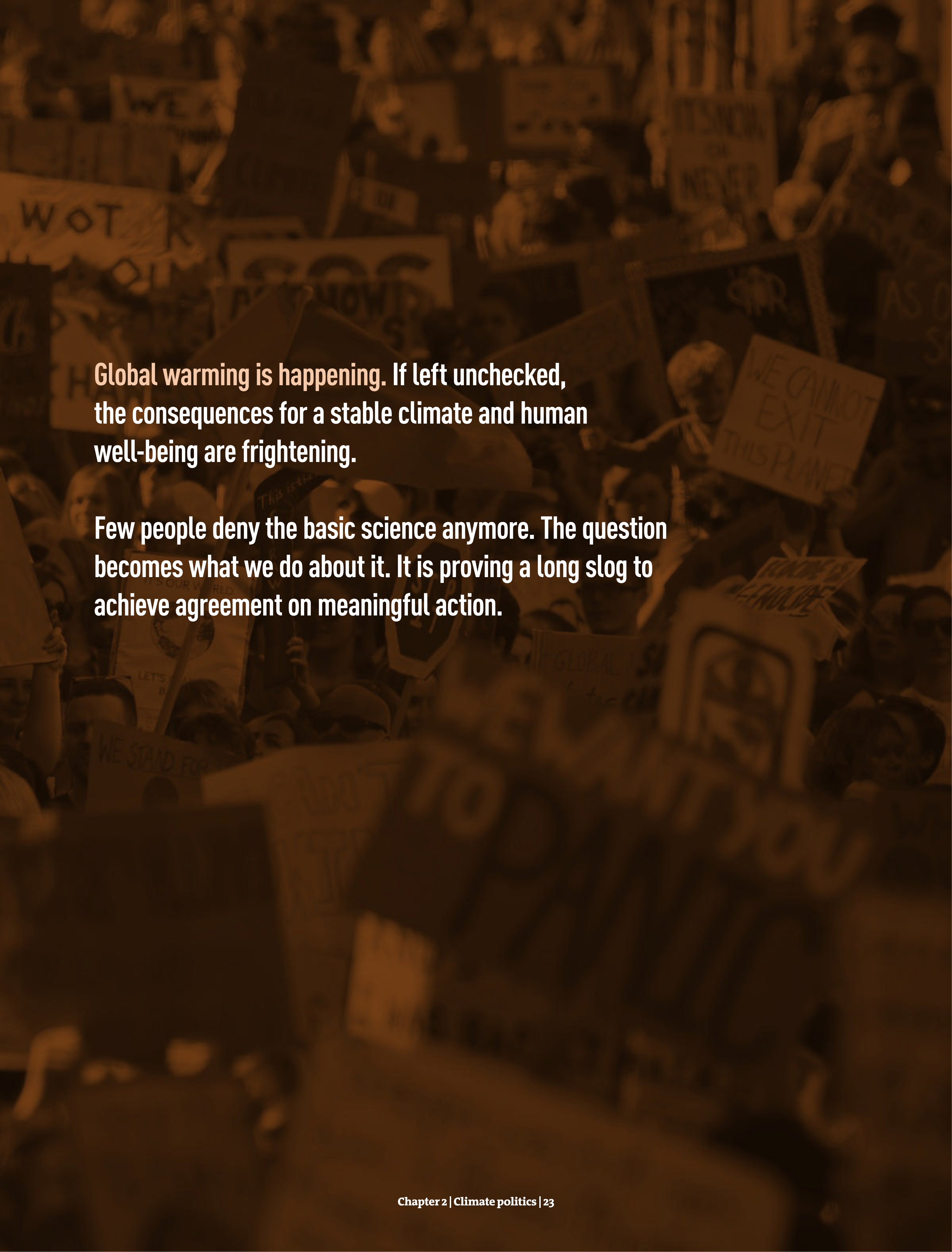
## CHAPTER 2

# CLIMATE POLITICS




WE CANNOT EXIT THIS PLANET

Global warming is happening. If left unchecked, the consequences for a stable climate and human well-being are frightening.

Few people deny the basic science anymore. The question becomes what we do about it. It is proving a long slog to achieve agreement on meaningful action.

# THE LONG ROAD TO CLIMATE ACTION

**International efforts to combat climate change are a thicket of acronyms: IPCC, UNFCC and COP. They are the products of a remarkable consensus about the dangers of global warming. That consensus has proved easier to achieve than agreeing on or taking action.**

IN 1965, a report from US president Lyndon Johnson's Science Advisory Committee reported rising levels of carbon dioxide in the atmosphere, for which "at least during the recent past, fossil fuel combustion has been the only significant source". The committee's environmental pollution panel warned that by 2000 this increase "may be sufficient to produce measurable and perhaps marked changes in climate" that "could be deleterious from the point of view of human beings".

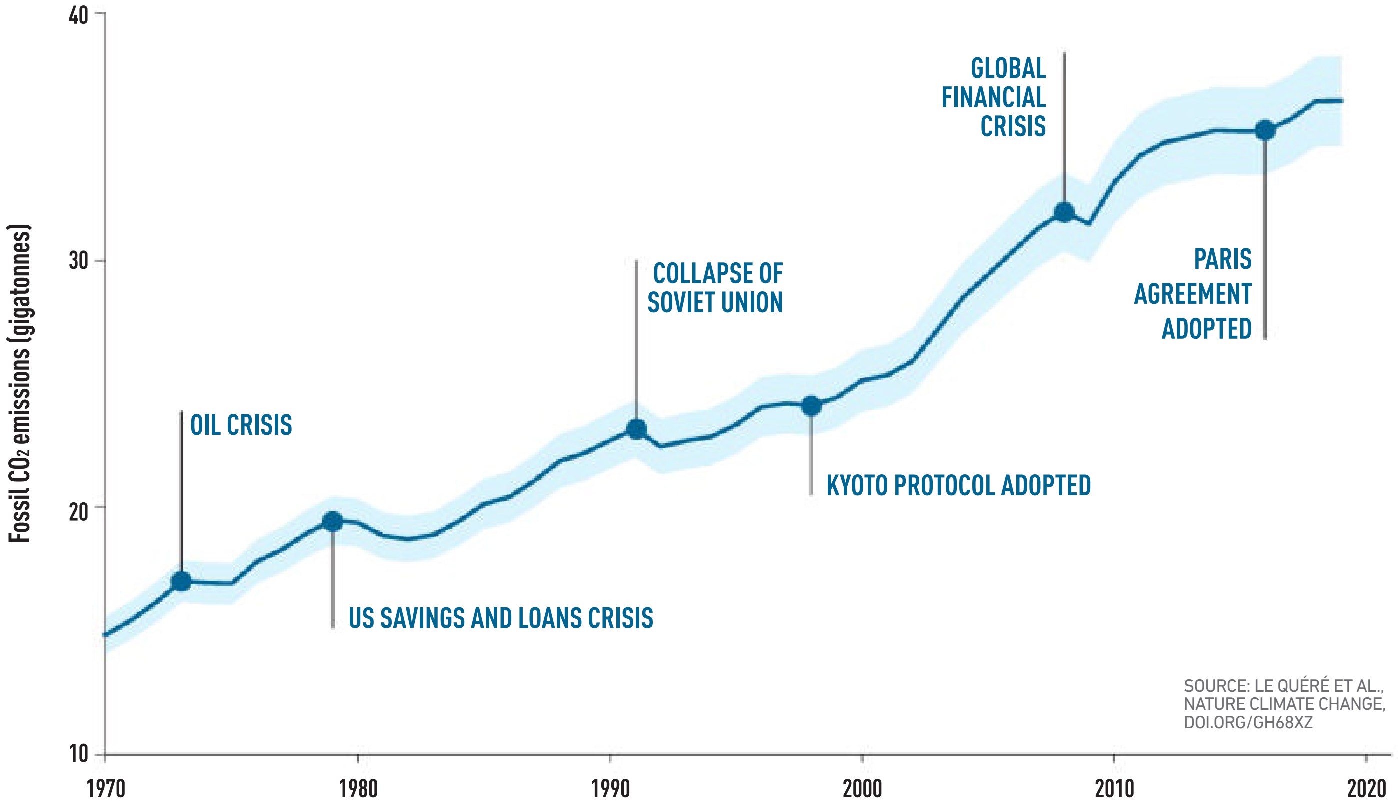
There are many reasons why we haven't heeded such warnings, not least a concerted campaign of disinformation on behalf of some fossil fuel companies. The first high-profile scientific warning about climate change came in 1988 from James Hansen, then the director of the NASA Goddard Institute for Space Studies, in testimony to the US Congress. That same year, the World Meteorological Organization and the United Nations Environment Programme established the Intergovernmental Panel on Climate Change, or IPCC. ›

→ Turn to page 89 for 33 more reasons why we fail to act on climate change

RIGHT:PETER SCHATZ/ALAMY STOCK PHOTO
PREVIOUS PAGE: STEVEN SCOTT TAYLOR/ALAMY STOCK PHOTO

ES IST NICHT DEINE SCHULD
CHANGE THE SYSTEM NOT THE CLIMATE
WARUM LERNEN OHNE ZU
LETS FUCK
THERE IS NO TIME TO CHOOSE
MAKE EARTH COOL AGAIN
KEINE TOLERANZ FÜR
Schatz sag mir was Schmutziges Kohleabbau
THERE IS NO PLANET B
KOHLE KOHLE
KOHLEAUSSTIEG
rECHTS ist
WE DON'T HAVE TIME
SAVE THE EARTH
There is NO Planet B
IT'S TIME TO CHANGE SOMETHING
THE CLIMATE IS CHANGING
KOHLE FÜR MOOS? BRUDER MUSS
ZWISCHEN NATUR UND WIRTSCHAFT
Lasst nicht die WELT
WENN WIR JETZT NICHT HANDELN GIBT ES KEINE ZUKUNFT
Waldis für Wald
KEINE KOHLE für KOHLE
ALLE WOLLEN ZUR NATUR, ABER KEINER ZU FUSS
RETTET MICH
Klimaschutz statt Kohleschmutz
THERE is NO
NATURSCHUTZ
Es ist unsere Zukunft, mit der ihr spielt
Ich bin so wütend ich hab sogar ein Schild
STOP KOHLE
WER EINEN FEHLER BEGANGEN HAT UND
#FFF
KLIMASCHUTZ STATT KOHLESCHMUTZ
Der KLIMAWANDEL wartet nicht
LASS IN ZOO DA GIBT'S NOCH EISBÄREN
ICH STEHE HEUTE HIER DAMIT
DIE DINOSAURIER DACHTEN AUCH SIE HÄTTEN NOCH ZEIT
Politikwende

The past decades have seen only minor blips in a relentless upwards trend of greenhouse gas emissions, fuelled largely by rapidly developing economies such as China and India playing catch-up with high-emitting economies in the West



SOURCE: LE QUÉRÉ ET AL., NATURE CLIMATE CHANGE, DOI.ORG/GH68XZ

The IPCC acts as a clearing house for research on the science of climate change and its potential natural, economic and political impacts. Since 1990, it has produced five weighty Assessment Reports summarising all we know. The last, AR5, came out in 2014; AR6 is due to appear in stages in 2021 and 2022.

International efforts to react to the science and take steps to tackle climate change began at the United Nations Conference on Environment and Development, informally known as the Earth Summit, in Rio de Janeiro in 1992. The treaty signed by 154 countries there, known as the United Nations Framework Convention on Climate Change, or UNFCCC, established an agency of the same name headquartered in Bonn. Its mandate is to seek international agreements to curb greenhouse gas emissions and so avoid dangerous global warming. Since then, an annual summit known as the Conference of the Parties, or COP, has been held to update on progress and agree next steps.

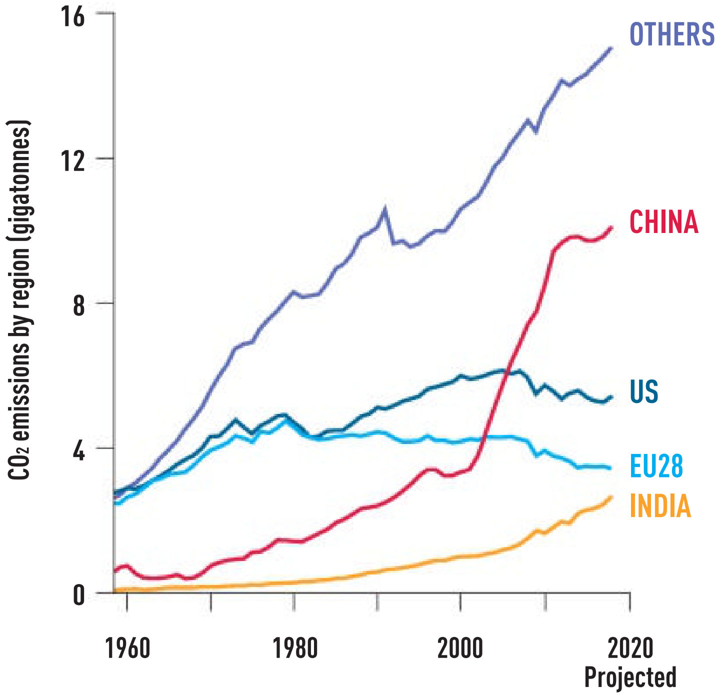
The first big move came at COP3, held in 1997 in Kyoto, Japan. The Kyoto Protocol, which officially came into force in 2005, required that developed economies – responsible for the vast majority of greenhouse gas emissions – should by 2013 cut them by an average of 5 per cent relative to 1990 levels.

Most beat their targets, with collective emissions falling by about 23 per cent. "The Kyoto Protocol was a remarkable achievement in many ways," said Christiana Figueres, who was head of the UNFCCC from 2010 to 2016, back in 2015. "We cannot link all these emissions reductions directly to the Kyoto Protocol, but it clearly played an important role in catalysing this promising trend, which led to a collective and very welcome 'over-achievement'."

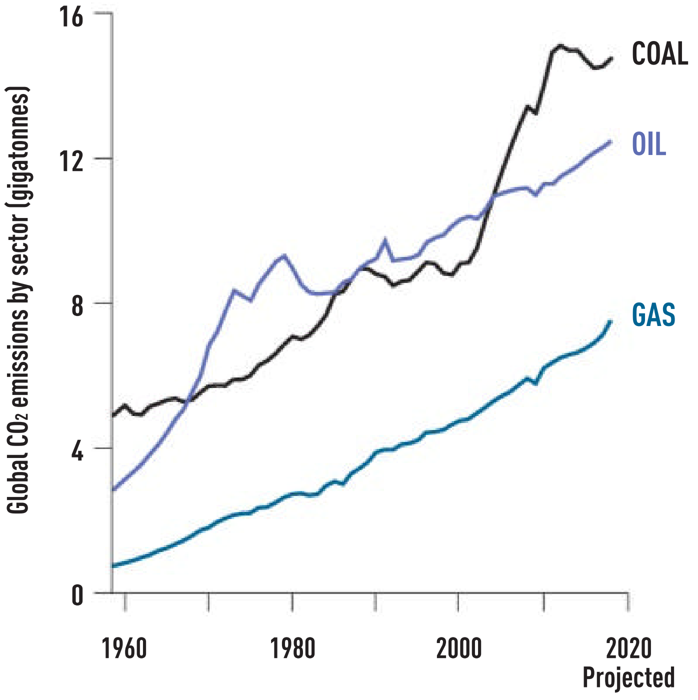
The protocol also put in place many frameworks central to climate action today. In particular, it laid the basis for carbon trading – allowing countries that cut or prevent $CO_2$ emissions to earn "carbon credits" that they can sell to other countries or companies that have exceeded their emissions targets.

But the Kyoto protocol was also full of holes. Its targets were not legally binding, and fell far short of what was needed to limit global warming to a "safe level", which itself was not defined. Many emissions reductions came from switching from burning coal to make electricity to other fossil fuels such as gas, that produce fewer emissions per unit energy, but still pump out $CO_2$. Two of the world's largest emitters of greenhouse gases, the United States and China, never ratified the protocol. While emissions from many developed economies have flatlined or fallen, overall greenhouse gas emissions have continued to climb as countries such as China and India develop their economies (see graphs, above).

More than 20 years of negotiations finally brought the first universal, legally binding agreement on global climate change at COP21 held in Paris, France, in December 2015. The Paris Agreement, which entered



SOURCE: G.P. PETERS ET AL.
NATURE CLIMATE CHANGE, VOL 10, 3–6
DOI:10.1038/S41558-019-0659-6



into force on 4 November 2016, has, as of January 2021, been ratified by the European Union and 189 states, including China, India and the US, that together are responsible for more than 97 per cent of global carbon emissions. The few exceptions include Turkey, Iran and Iraq; the decision of the US to abandon the agreement in 2017 following the election of Donald Trump was overturned within hours of the inauguration of his successor, Joe Biden, in January 2021.

The long-term goal of the Paris climate agreement is to stop global temperatures from rising 2°C above pre-industrial levels this century, and to aim to limit the increase to 1.5°C. This 1.5°C target is a more ambitious goal than was expected before the summit. Many scientists at the time pointed out that the agreement did not go nearly far enough to achieve these aims. Were countries to stick both to the spirit and letter of the agreement, global warming could be limited to under 4°C, perhaps even under 3°C, but no more.

However, the agreement did contain a "ratchet mechanism". Countries must state every five years what they are doing to tackle climate change, known as their nationally determined contribution or NDC. Each successive NDC "will represent a progression beyond" the country's previous one. The agreement also emphasises the need for global carbon emissions to peak as soon as possible, and for countries to undertake rapid reductions thereafter in accordance with the best available science. ▮

## WHY 1.5°C?

The 1.5°C climate target was picked not because it is the right number, but because it was convenient. A 1990 report concluded that limiting global warming to 1°C would be safer than a 2°C cap. But in 1996, with 1°C already looking out of reach, 2°C was adopted as a target by the European Union's Council of ministers. This led to its 2010 adoption by the UN.

When the Paris climate agreement was being negotiated in 2015, island nations facing watery oblivion demanded a more ambitious target. Since the world was already around 1°C warmer by then, 1.5°C was chosen. But as the IPCC made clear in a report on the 1.5°C target published in 2018, it is not a safe limit. The climate change impacts we are already seeing, from more extreme weather to dying corals in the oceans, indicate "safe" truly is a matter of degree.

→ Chapter 3 has more on climate impacts

ALAN MORRIS/ISTOCK

Preserving carbon sinks such as peatlands, here in Shetland, UK, is crucial to net-zero emissions

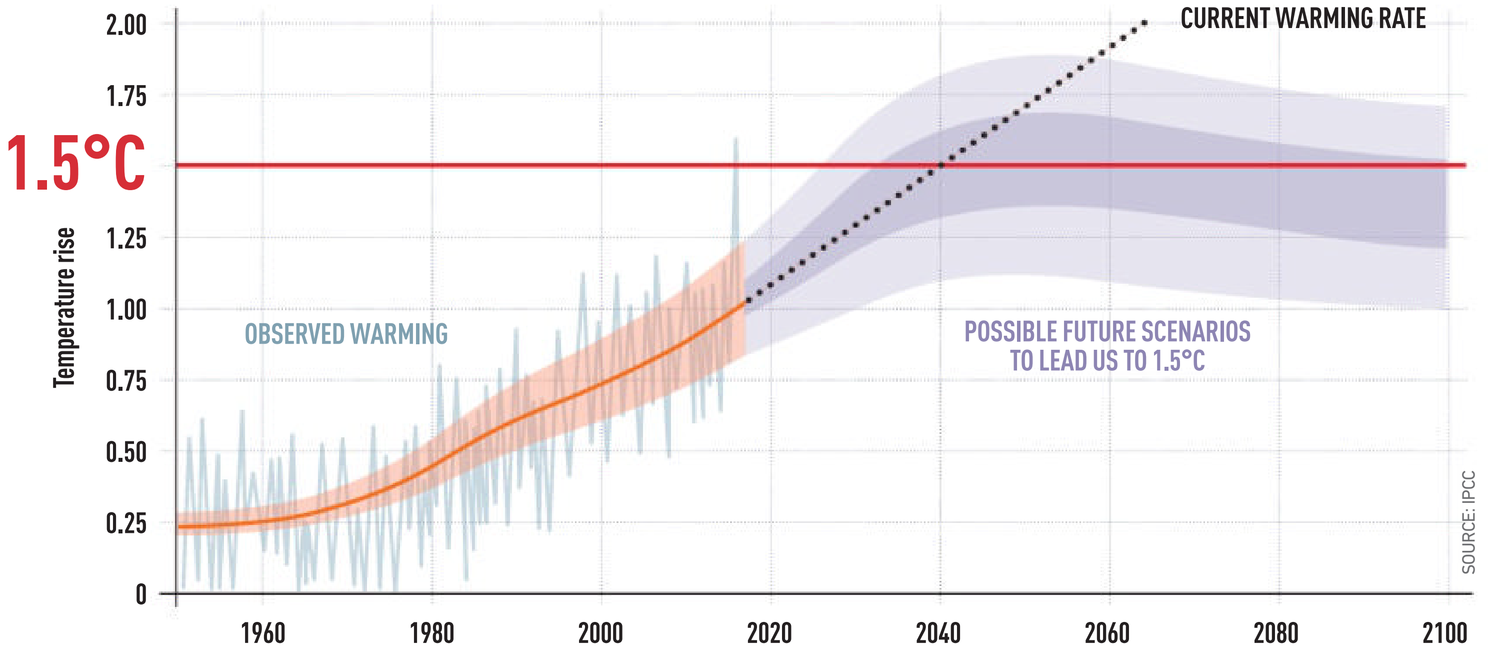
"Net zero" is the big buzz phrase around current efforts to limit global warming. But what exactly it means, and what mechanisms we can use to get there, are matters of intense debate.

# NET-ZERO EMISSIONS

THE concept of net-zero greenhouse gas emissions was first popularised by the Paris Agreement agreed in 2015. At the watershed COP21 meeting, nearly 200 countries agreed "to achieve a balance between anthropogenic emissions by sources and sinks of greenhouse gases in the second half of this century"; in other words, to be emitting no more carbon dioxide or other greenhouse gases than Earth's natural systems can absorb by some time between 2050 and 2100.

An IPCC special report on hitting the 1.5°C target published in 2018 upped the ante. It concluded that for global warming to be limited to 1.5°C, global net human-caused emissions of $CO_2$ would need to fall by about 45 per cent from 2010 levels by 2030, reaching net zero around 2050. That report helped

Most climate scenarios see us overshooting a 1.5˚C temperature rise and then bringing global temperatures back down



SOURCE: IPCC

spur countries including Sweden to legislate a goal of net-zero emissions by 2050, followed by the UK in 2019, the first major economy to do so. In 2020, China, the world's biggest emitter, pledged it would reach "carbon neutrality" by 2060. Businesses, and sub-national actors such as states and regions, have also set similar targets.

Why net zero, rather than just zero? That's because even if we decarbonise our electricity grids entirely, make green hydrogen production affordable and dramatically scale up carbon capture and storage, there will still be a rump of emissions left by 2050. Most of those will come from hard- or impossible-to-abate sectors including farming, aviation, some heavy industry and waste.

That is where greenhouse gas removals come in. Tree-planting, restoring peatlands and technologies such as direct air capture of $CO_2$ can tip the carbon accounting scales to cancel out the remaining rump, leaving a country or business at net zero. Most realistic scenarios that lead to 1.5°C of warming see a temperature overshoot by mid-century, with the use of negative emissions to bring the warming down to 1.5°C by the end of the century (see graph, above).

→ Chapter 4 has more on solutions to hit net zero

There are a few technical but important questions around the best ways to achieve net zero. One is whether carbon credits from other countries, of the sort introduced by the 1997 Kyoto Protocol, should be allowed to count towards a country's progress. The UK government's advisers, the Climate Change Committee (CCC), argues they should not, because of the expense but also because all countries will eventually need to reach net zero, so that option will vanish. Another is whether net zero should cover just carbon emissions or all greenhouse gas emissions, including others such as methane, which comes principally from farming and oil and gas production. The CCC says it is better to cover all greenhouse gas emissions.

The devil can still be in the detail. In 2021, former Bank of England governor Mark Carney, now an advisor to both the UN and the UK government on climate change, stirred controversy by appearing to suggest that the firm where he works, Brookfield Asset Management Inc, was net zero because its investments in renewable energy "avoid emissions", despite the firm also holding major investments in coal, oil and gas. Carney later rowed back on the claim. "Greenwash" from countries and companies is still a major concern. The UK, for example, made its target law in June 2019 but is still off-track to meet even its near-term targets for the mid-2020s, let alone long-term net zero by 2050. ▮

# COP26 AND COVID-19

**November 2021's COP26 climate conference in Glasgow, UK, will be a crucial moment for agreeing meaningful climate action. It was delayed for a year by the covid-19 pandemic, a global crisis that has in some ways changed the framing of the climate crisis – and in other ways not.**

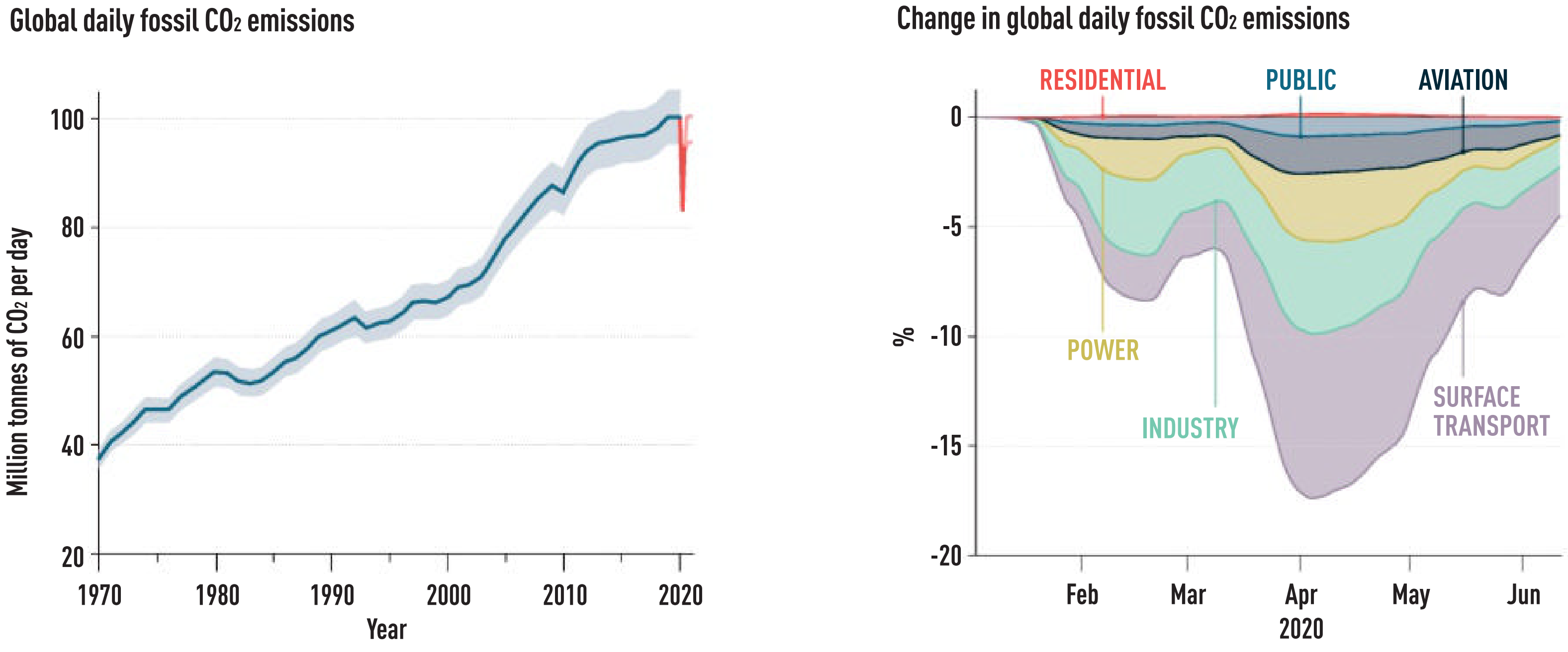
COP26 is the most important "conference of parties" to the UN Framework Convention on Climate Change (UNFCC) since COP21 in Paris in 2015. Thousands of delegates are expected to descend on Glasgow, UK, between 1 and 12 November. The aim of the summit, and the negotiations leading up to it, is to elicit much bolder action to bring down greenhouse gas emissions in line with the aspiration to limit global warming to 1.5°C.

It was delayed for a year by a global pandemic that shunted all other emergencies to the sidelines. "Climate change [was] put on the back burner," says climate scientist Corinne Le Quéré at the University of East Anglia, UK, who advises the UK and French governments. On the plus side, global greenhouse gas emissions dropped 17 per cent in April 2020, the first full month after the global pandemic was declared. Most of the decline was from less road and air travel, and from industry shutting down, especially in China (see diagram, opposite). Emissions had crept back closer to normal by June, but global emissions declined between 4 and 7 per cent in 2020 – the biggest annual decline since the second world war.

As Le Quéré notes, however, the higher figure is roughly, but not quite, the annual decrease of 7.6 per cent needed to check warming at 1.5°C – every year until 2030. And carbon dioxide levels in the atmosphere have continued to rise. Piers Forster at the University of Leeds in the UK has estimated that 2020's covid-19 restrictions will have a global cooling effect of just 0.01°C by 2030, if we return to business as usual. Staying at home and grounding planes only goes so far without simultaneous systemic change to industry, transport and power generation. "We aren't going to make the necessary changes without much longer infrastructure change and the whole structural changes to the way economies work," he says.

The point of COP26 is to – finally – reach agreement on just those changes. The UK government, which is

**The covid-19 pandemic lockdowns brought about an unprecedented drop in $CO_2$ emissions from fossil fuel burning – but they have since returned to almost where they were before**



Global daily fossil $CO_2$ emissions

Change in global daily fossil $CO_2$ emissions

SOURCE: LE QUÉRÉ ET AL. NATURE CLIMATE CHANGE (2020); GLOBAL CARBON PROJECT; FIGURE: @JONES_MATTW

co-hosting the summit with Italy, has laid out four objectives. It wants every country to: commit to hit net zero by 2050, as the UK did in 2019; ensure protection for the people most vulnerable to a warming world; deliver a $100 billion a year climate finance pledge from richer nations to help lower-income countries adapt to and fight climate change; and increase collaboration across business, civil society and nations.

Key to the success or failure of the summit are the national emissions-reducing plans known as nationally determined contributions (NDCs). Following the ratchet mechanism agreed in Paris, countries were originally supposed to submit new NDCs by the end of 2020. The pandemic, plus heel-dragging by the world's biggest emitters, derailed that timeline. By the time of a UN assessment in February, only 74 countries, representing 30 per cent of global emissions, had submitted a new climate plan.

Worse still, despite the EU, UK and others having put forward stronger plans, a UN report early in 2021 calculated that current pledges would cut emissions by just 0.5 per cent compared with 2010 levels by 2030, a far cry from the 45 per cent needed to limit warming to 1.5°C.

The UN has called on countries that submitted national climate plans before the end of 2020 to review them. In April, US president Joe Biden announced a target of a 50 to 52 per cent reduction in emissions compared with a 2005 baseline by 2030. China announced in 2020 its intention of reaching peak carbon emissions in 2030, and subsequently cutting them in half by 2060, but is yet to set out how it will do it. To meet its goals, China's emissions needed to start decreasing in 2020. In reality, it was the only major economy where emissions grew, despite the coronavirus pandemic.

As the four biggest emitters, the EU, the US, China and India will be the key players at COP26. But other groupings of nations will be crucial too, including the alliance of small island states most affected by sea level rise and the G77 grouping of developing countries.

Perhaps the biggest issue is finance. The $100 billion pledge was originally agreed at COP15 in Copenhagen, Denmark, in 2009, to be delivered by 2020. Only about $80 billion is currently on the table. This matters because international climate negotiations rely on consensus decision-making and goodwill, and actions to cut emissions in some national climate plans are conditional on financing. Agreement also needs to be reached on creating an effective global carbon-offsetting market, a key bone of contention left over from 2019's COP25 in Madrid, Spain.

For all the lack of meaningful progress so far, the current executive secretary of the UNFCCC, the former Mexican foreign minister Patricia Espinosa, is optimistic. "What we have seen in terms of transformations in the last two years is unprecedented," she says. "If we think about the way solar energy has evolved, and other types of renewable energies have evolved, the way people were able to adapt to a completely new reality out of the pandemic in such a short time, I think we can be hopeful." ▮

# "THERE IS NO REAL OBSTACLE OTHER THAN WITHIN OURSELVES"

**The emissions drop brought by covid-19 won't last, says climate scientist Corinne Le Quéré – unless we act to make it last.**

## PROFILE
## CORINNE LE QUÉRÉ

Corinne Le Quéré is a French-Canadian climate scientist at the University of East Anglia in Norwich, UK. She is an adviser to the UK and French governments, both of whom have committed to reach net zero by 2050.

**What do you expect will happen to global carbon dioxide emissions after the pandemic?**

Over the past decade, emissions had been going up about 1 per cent per year. Our estimates suggest a reduction in emissions [during the 2020 lockdowns] of between 4 and 7 per cent. This is huge. In 2009, during the financial crash, emissions dropped 1.4 per cent. They then grew more than 5 per cent in 2010, which brought us exactly back to where we were like nothing had happened. There is a big risk for that now as well.

**Which way do you think the post-coronavirus economic recovery will go?**

It could be that governments do exactly what they know best, like build roads and finance the big carbon-emitting industries. But there is an opportunity to invest in the green economy. Renewable energy is a lot cheaper than in 2010 and we have all the knowledge required to make the batteries that can store that energy. Will that happen? Possibly in the UK. I would say even probably in Europe. It's not a given, but the signs are reasonably good. Whether it will happen worldwide is a bigger question.

**What lessons, if any, does the covid-19 crisis hold for our efforts to avoid dangerous warming?**

First to take risks seriously – and the fact that we're very vulnerable. The UK is vulnerable because we have so many inequalities in society, and you can see how the crisis hits poor people harder. We have to rebuild society in a way that makes it a lot more resilient to

Government investments post-coronavirus should focus on resilience, says Corinne Le Quéré

REUTERS/ALAMY STOCK PHOTO

climate-related events. I think what's happening also reveals that behavioural change is not enough. The vast majority of emissions remain, and the only way to reduce those is with structural changes to economies and industries.

### In terms of cutting emissions, what are some of the things that we have been doing during lockdown that might be worth continuing?

When we go back to work, it is going to be problematic because social distancing is difficult on public transport. We have to instead encourage those who can work at home to do so, and to get as many people as possible who can't to cycle or walk to work. Electric bikes are increasingly affordable, which opens the possibility of cycling from suburbs in a way that didn't exist before.

### What about flying?

Aviation has always been very problematic for climate change. There's no credible way to have net-zero emissions by 2050 and aviation as it was before covid-19, and the industry didn't engage at the right level on cutting emissions. Before this crisis, the push was for bigger airports and so on. Now, with covid-19, the number of flights has been cut by 75 to 80 per cent.

So now we have the opportunity to ask: what is an appropriate number of flights? We could have some leverage, too. The aviation sector has had exonerations for taxes that were completely unjustified. They haven't had the net-zero target, which is also unjustified. So I think these are the two levers governments can use when awarding recovery packages to aviation companies.

### How should governments take advantage of the opportunity to rethink economies and societies?

Government investments post-coronavirus should focus on those actions that both support workers and enable the structural changes needed to deliver net-zero emissions, so we are more resilient in the future. In terms of investments, these should include support for the full electrification of transport, massive renovations of buildings and tree-planting and restoration of natural habitats. Actions that lock us into fossil fuels, such as building roads, should clearly be avoided.

### One of the big messages that picked out of the IPCC special report in 2018 was that there were "12 years to save the world", to ensure global warming doesn't exceed 1.5°C. How helpful was that?

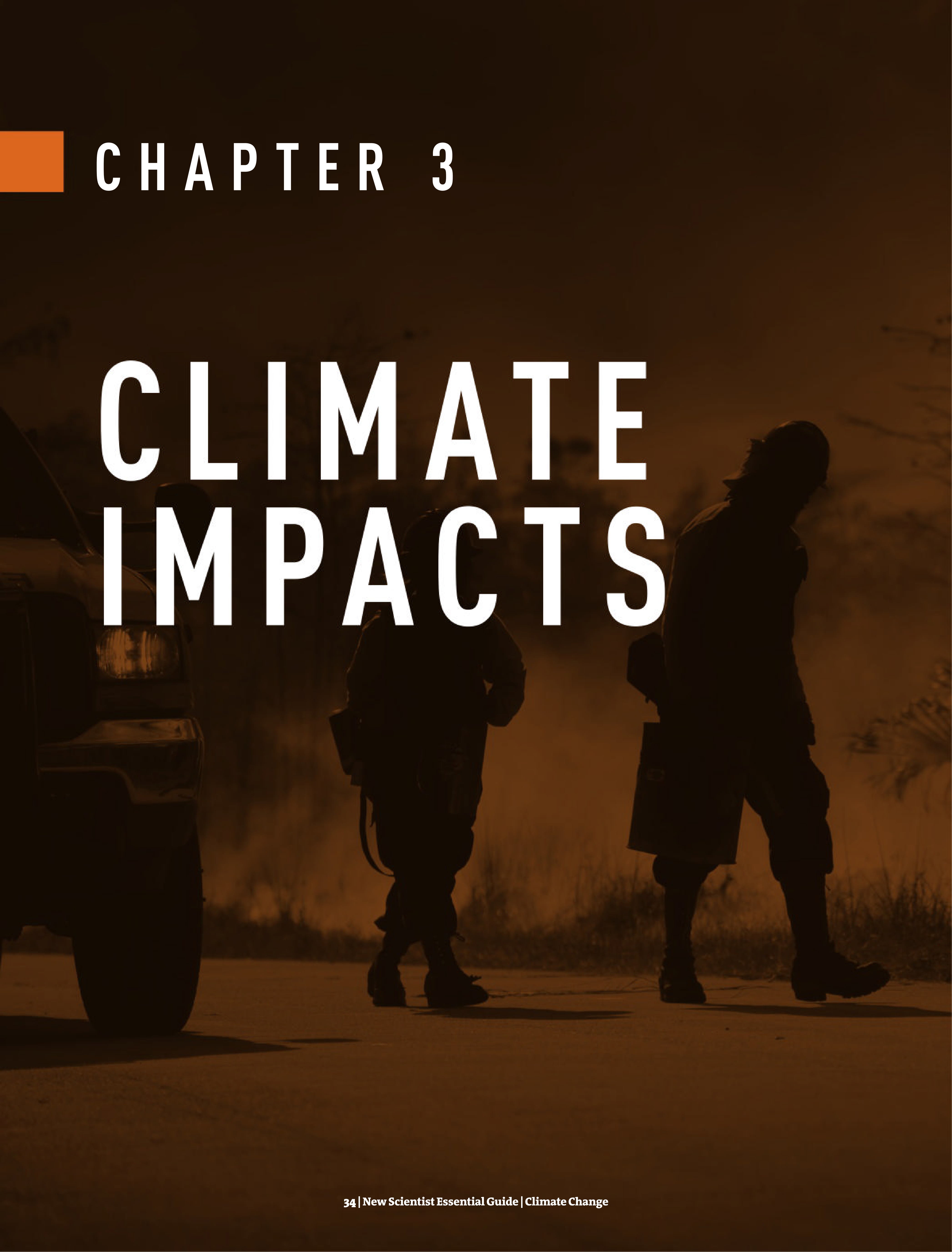
I didn't find it super helpful. What are you going to do in 10 years' time? You're just going to hope people will have forgotten you've ever said that. I understand that it gave a sense of urgency that wasn't there before, but it's not 12 years anymore. I'm going to work on climate change all my life. If we miss the 1.5°C target, then I will fight for 1.6°C or 1.8°C, and if we miss the 2°C target, I will fight for 2.4°C. So for me, the fight is permanent. The lower the level we're fighting for, the better it is. There are some degrees of warming I don't even want to think about.

### You said in 2018 that before you die, you think you will live in a world where people no longer eat animals and can breathe clean air in the middle of cities. Do you still think that's the case?

The state of the science is clear. We have the Paris Agreement. We've had all the youth coming up and saying "we want a better world". We're not over the big polluting phase, but we've progressed in our thinking enormously. There is no real obstacle other than within ourselves. ▮

## CHAPTER 3

# CLIMATE IMPACTS



With the world already warmed by something like 1°C, some of the effects of climate change predicted by models are already being felt.

Increasing temperatures are just the start. From more extreme storms and wildfires to melting ice and changes to the world's oceans, significant changes are already baked in, whatever action humanity takes to curb climate change.

# DEADLY HEAT

**Most of us fail to take the "warming" in global warming seriously. If you live somewhere temperate, you might even welcome a rise of a few degrees as offering more opportunity for picnics, barbecues and relaxed afternoons in pub gardens. But even now, heatwaves kill.**

RIGHT: OLENA SAKHATSKA/ISTOCK
PREVIOUS: PGIAM/ISTOCK

IT WAS an astounding temperature recorded in Lytton in British Columbia on 29 June 2021, shortly before the village was consumed by a wildfire. The mercury hit 49.6°C, a record for Canada, and the world's highest temperature ever recorded north of 45°N.

Such records are falling wherever you are in the globe. In Australia, January 2017 was the hottest ever recorded in Sydney and Brisbane, and great swathes of the south-east endured temperatures that often exceeded 40°C for weeks on end. In January 2018, the temperature in Sydney briefly climbed to over 47°C. Climate models see both it and Melbourne experiencing heatwaves with highs of 50°C by 2040. "Going out to 40 or 50 years, basically [such summers] will be normal," says Sarah Perkins-Kirkpatrick at the Climate Change Research Centre of the University of New South Wales (UNSW). "It hasn't really sunken in yet in Australia."

In 2020, temperature records tumbled in one of Earth's coldest places. The symbolic milestone of 100°F was passed in the Siberian town of Verkhoyansk in June, on the way to a record high of 38°C. "The heat was extreme, but... also very persistent, persisting since January," says Samantha Burgess at the EU-sponsored Copernicus Climate Change Service (C3S). The

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heatwave was made at least 600 times more likely by climate change, according to research by Friederike Otto at the University of Oxford and her team.

In 2020, Death Valley in California saw an air temperature of 54.4°C, the hottest ever recorded in the world, if verified – until it was fractionally exceeded in July 2021. Also in 2020, Phoenix in Arizona saw 53 days with highs of 43.3°C (110°F) or more. The previous record was 33 days in 2011. Such a leap shows that climate change isn't always linear. "That's an example of this step function: an exponential jump, not a little creep. We've seen that with wildfires, damages, and now with temperature extremes and consecutive days of extremes," says Adam Smith at the US National Oceanic and Atmospheric Administration (NOAA).

"The biggest change we see from climate change is on temperature, and there climate is an absolute game changer," says Otto. "Even at 1°C warming, climate change is bringing us to the edge, or even over the edge, of what we are able to cope with."

In the US, extreme heat caused more fatalities between 1978 and 2003 than earthquakes, hurricanes, floods and tornadoes combined. By some estimates, a 2003 summer heatwave centred on France killed over 70,000. In 2017, the medical journal *The Lancet* published a report concluding that we face a "looming public health emergency". Already, 30 per cent of the world's population experiences potentially deadly temperatures for at least 20 days every year. A team led by Camilo Mora at the University of Hawaii in Manoa concluded that this will rise to nearly 75 per cent by 2100 if we do little to limit greenhouse gas emissions.

What matters here is not the air temperature, but the temperature you experience. You can survive for a while at well above 50°C, as long as you can sweat effectively. The problem is humidity. "The only way you lose heat when you sweat is by turning liquid into vapour. It has to evaporate," says Graham Bates at Curtin University in Western Australia. "With a humidity of 90 per cent, the air is almost saturated, and when you sweat it just drips off, and you won't lose heat."

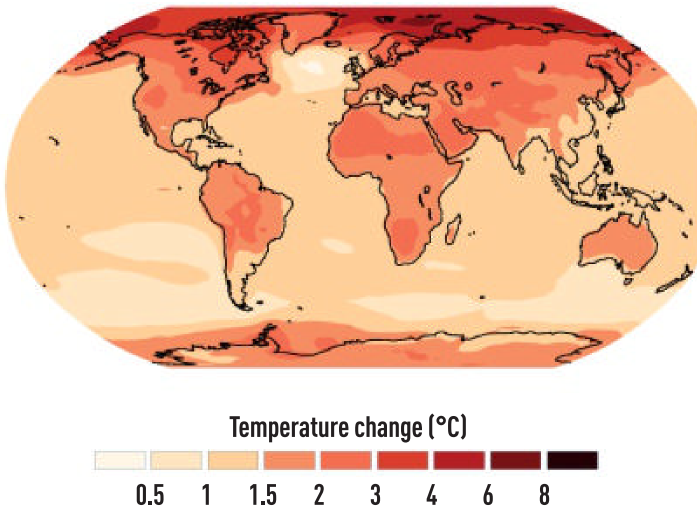
A "wet bulb temperature" of 35°C – equivalent to an ambient temperature of 35°C and 100 per cent humidity or 40°C and 75 per cent humidity – is considered the limit for human survival. Above this, even a healthy person in the shade won't live longer than 6 hours. Nowhere on earth has experienced it yet, although Bandar Mahshahr in Iran got very close in July 2015 with 46°C and 50 per cent humidity. But it is only a matter of time.

"Both temperature and humidity are going up," says Steven Sherwood, an atmospheric scientist at UNSW. The highest risk is in places that are already humid, such as the Amazon and the Indus valley and many tropical countries. Research published in August 2017 showed that parts of India, Pakistan and Bangladesh could occasionally exceed a wet bulb temperature of 35°C by the end of this century. This region is home to 1.5 billion people, about a fifth of the world's population, most of them poor. Subsistence farmers will be disproportionately affected by crop failures. Yields of wheat, rice and maize are forecast to fall by between 3 and 7 per cent for each 1°C rise in global temperatures, while rising temperatures will also impact the productivity of rural labourers. Since 2000, global warming has effectively reduced the workforce in India by 418,000, according to *The Lancet* report.

The US National Weather Service classifies any wet bulb temperature above 31°C, likely to be reached in many places before the end of the century, as "extreme danger". That's because when we move, our muscles lose 90 per cent of their energy as heat. "The minute you start walking or running in the heat, then you take on a heat load which has to be

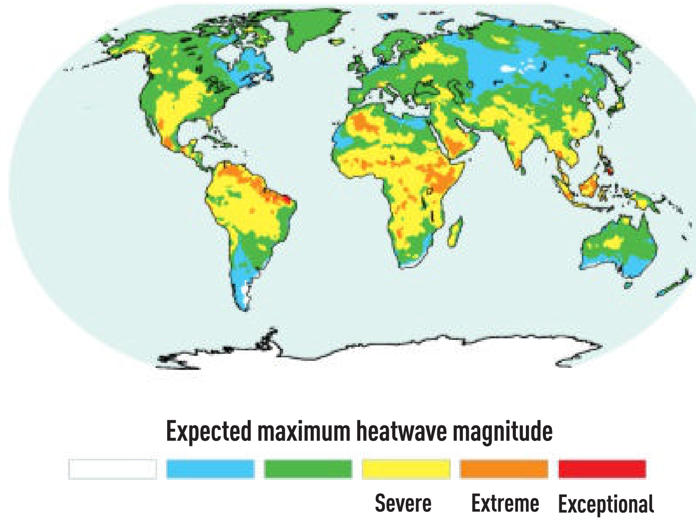
**The impacts of 1.5°C warming will not be evenly distributed**

The greatest warming will occur towards the poles and in continental interiors



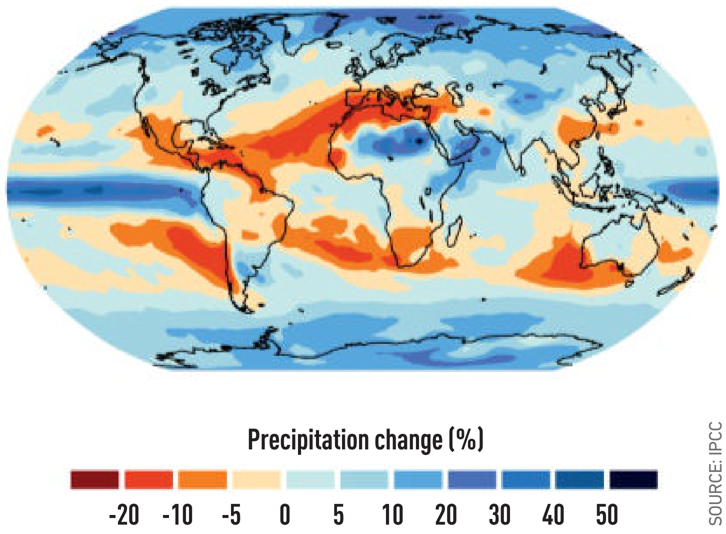
SOURCE: IPCC

The severest heatwaves, meanwhile, will occur in tropical regions that are already hot



SOURCE: DOI.ORG/CX23

Tropical and polar latitudes will see more precipitation while mid-latitude regions such as the Mediterranean will see more droughts



SOURCE: IPCC

dissipated to the environment," says Bates.

That's why most deaths from overheating are often simply recorded as heart failure, because the heart must work overtime pumping blood to the extremities. Elderly people are particularly susceptible because they often have weak hearts and their skin is less effective at sweating. Children are at greater risk too as their smaller bodies take less time to heat up and they have a larger surface-area-to-volume ratio, meaning they absorb heat more readily.

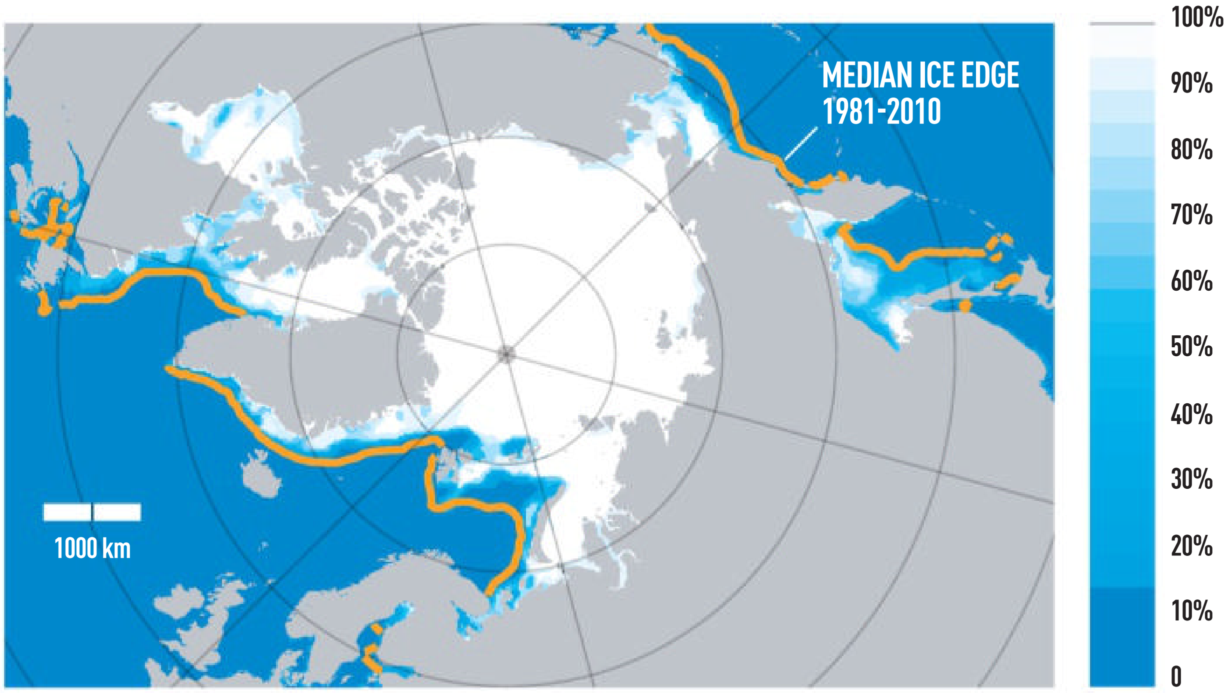
Adaptation to reduce the impact of rising temperatures will be key. Heatwaves are often most intense in cities, where asphalt and the dark roofs absorb more of the sun's rays and create a "heat island" effect. Urban planners rarely consider this, even in hot, wealthy places, such as Melbourne or Abu Dhabi. "We need to design our homes better. That's a starting point," says Perkins-Kirkpatrick.

She would like to see more white roofs to reflect sunlight and better insulation and double glazing so that, even without air conditioning, our homes are places we can retreat to in extreme conditions. Cities also need more shady, green spaces to help minimise the heat island effect. A trailblazer here is New York City, with a massive regreening programme in Manhattan over the past few years. The creation of air-conditioned public refuges is another option that has been discussed in Australia.

Such measures are likely to be necessary in many places sooner or later. With a temperature rise of just 1.5 to 2°C, as agreed under the 2016 Paris climate change deal, summer in parts of Australia will effectively become one long heatwave by 2100. Some tropical regions could go into a semi-permanent heatwave state. And the situation will be far worse if greenhouse gas emissions are not curbed. Then the heat could be well and truly on. ▮

# POLAR PERIL

The Arctic and Antarctic, though inhospitable to humans, are vital to stabilising Earth's climate – and they are at the sharp end of global warming. In the one, the danger signs are already all too clear. In the other, the risks are incalculable, in all senses.



Concentration of sea ice on 23 March 2021

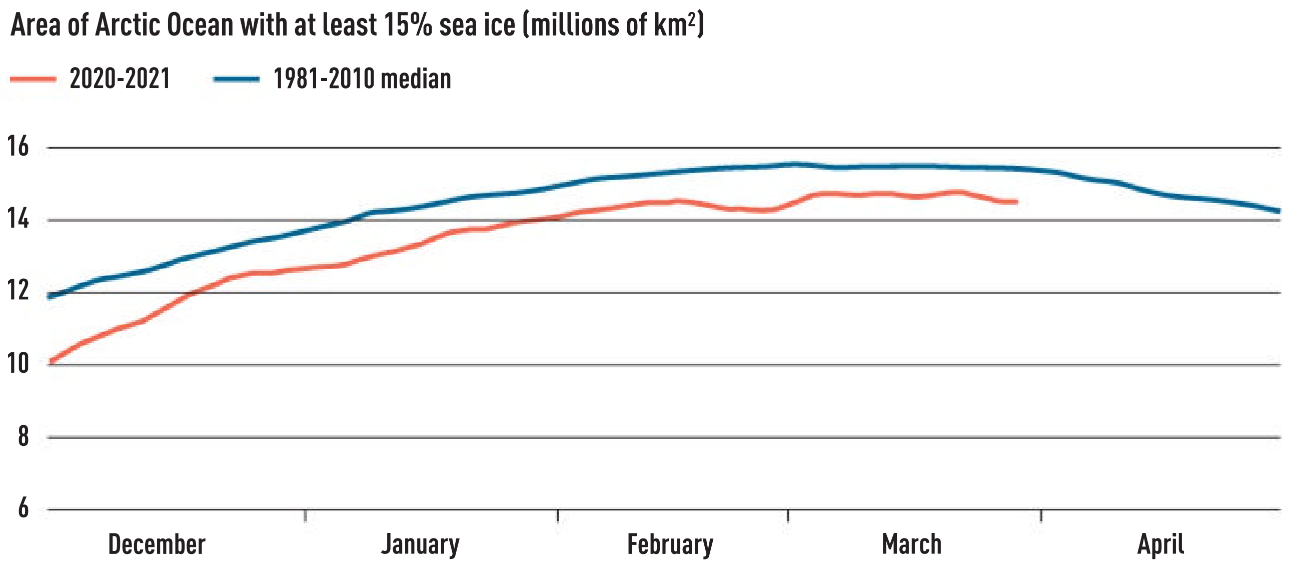
SOURCE: NSIDC

Arctic sea ice cover is trending downwards over decades (above right), while the edges of the Arctic ice sheet are retreating northwards (left)

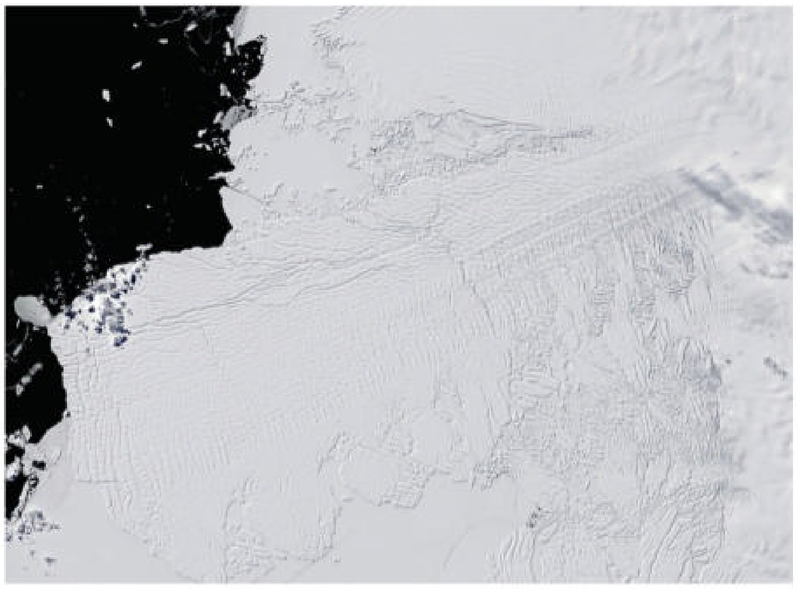
THE top of the world is heating faster than anywhere on the planet. The area of the Arctic ocean covered by ice has seen a long-term decline in the era of satellite measurement from 1979, losing 540,000 square kilometres per decade, an area the size of France. As shiny ice melts, dark water absorbs more of the sun's heat rather than reflecting it. Over the past 30 years, this change corresponds to a warming equivalent to a quarter of all the carbon dioxide released by human activity during that time.

What happens in the Arctic doesn't stay in the Arctic. The Greenland ice sheet alone contains enough water to raise global sea levels by 6 metres. Melting Arctic soil and sediment, or permafrost, is releasing more and more $CO_2$ and methane into the atmosphere. An estimated 1 trillion tonnes of carbon are in the top 3 metres of Arctic soils. If only a small fraction of this reaches the atmosphere, it will overwhelm any human emissions cuts. Methane is already streaming out of the seabed as microbes break down thawed organic matter. "The fear is that this will grow from being a set of methane plumes to an outbreak," says Peter Wadhams of the University of Cambridge, UK.

Arctic warming is playing havoc with weather systems in the northern hemisphere, too, by weakening the fast-flowing, high-altitude air current known as the polar jet stream. The result is more "blocked" weather patterns, and corresponding droughts, heatwaves such as that seen in Siberia in 2020 and catastrophic floods as in Germany in July 2021. The economic impact of unmitigated Arctic warming by the end of this century was recently estimated to be $67 trillion. As US congressman Jerry McNerney says: "When it comes to the Arctic, we're in deep shit."

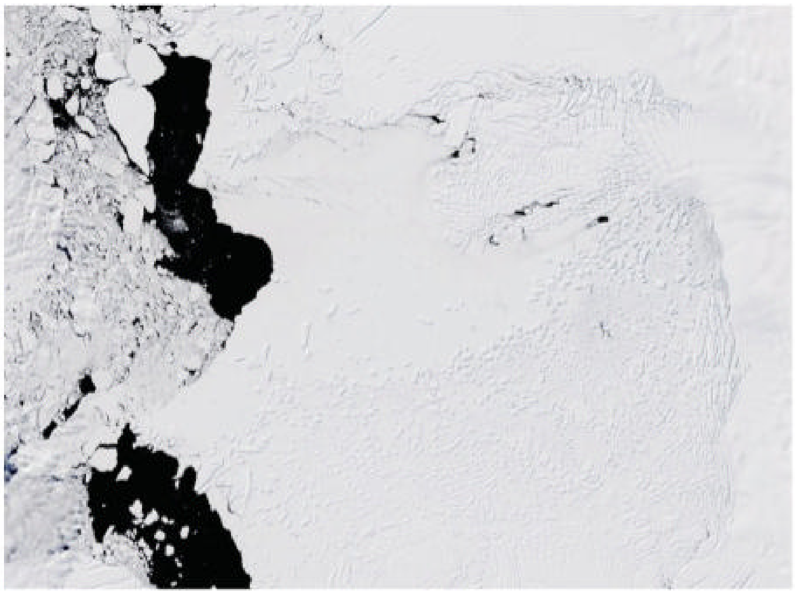


SOURCE: US NATIONAL SNOW AND ICE DATA CENTER: NSIDC.ORG/ARCTICSEAICENEWS



NASA EARTH OBSERVATORY

The stability of Antarctica's Thwaites Glacier has been in the spotlight in recent years. In this image from 2 December 2001 it is still largely intact



NASA EARTH OBSERVATORY

By 28 December 2019, the glacier had begun to melt and separate where it meets the sea. What this means for its long-term future is unknown

↓ The next section has more on extreme weather

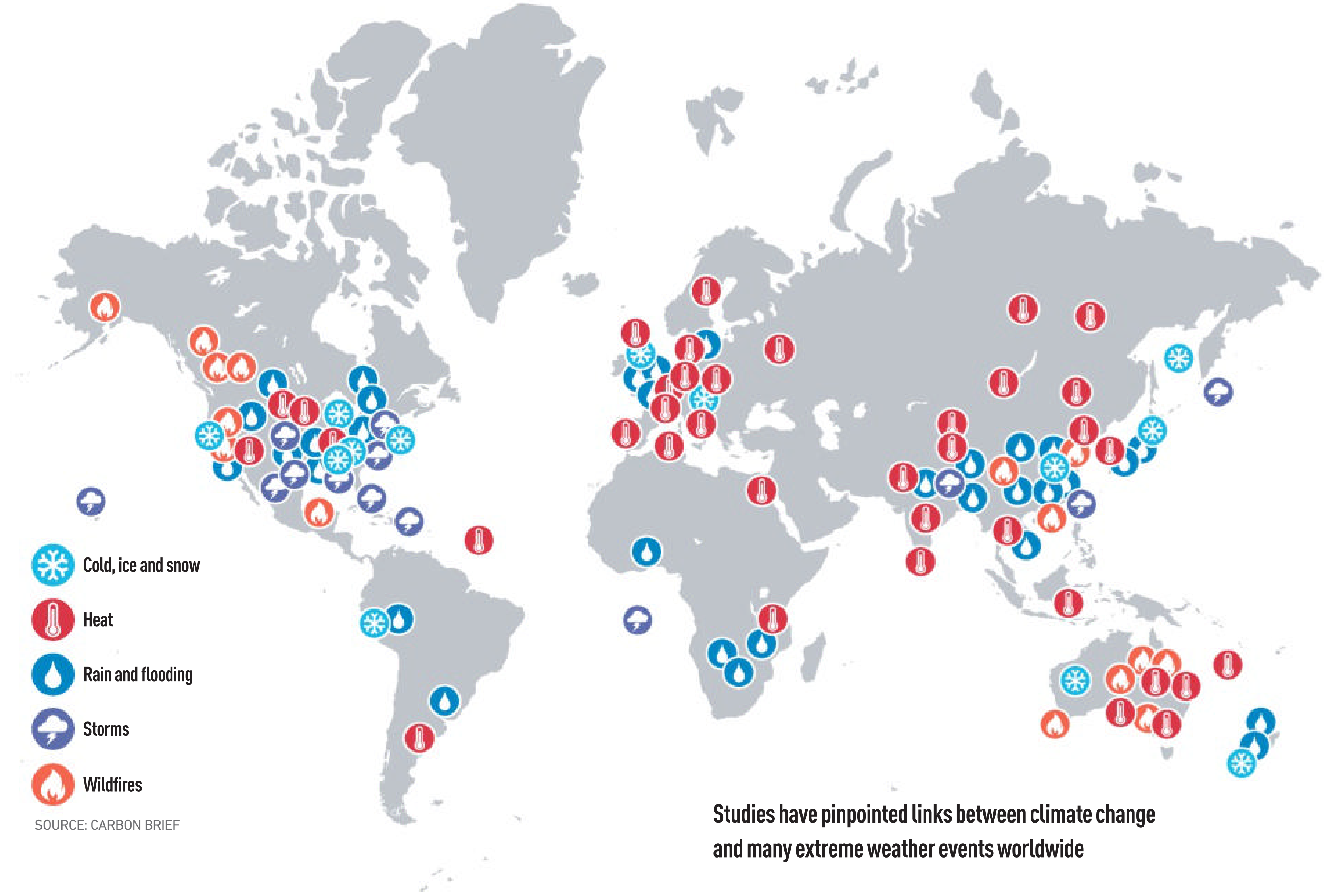
It gets potentially even deeper in the Antarctic. Unlike the Arctic sea ice, Antarctic sea ice has grown a little over the period of satellite measurements, probably because of changing wind patterns. But behind that there are alarming indications are that the vast continental Antarctic ice sheet is increasingly fragile.

Current concern centres on the Thwaites Glacier, a vast glacier about the size of Great Britain. It has been shrinking since the early 1990s, but ice loss has almost doubled over the past 20 years. It is now shedding a dizzying 35 billion tonnes a year. On its own, the glacier's collapse would raise seas by around 65 centimetres. But if Thwaites goes, the worry is it could trigger a wider collapse of the entire West Antarctic ice sheet – enough to raise seas by a calamitous 3.3 metres within a few hundred years. "What happens at Thwaites affects the whole ice sheet," says Sridhar Anandakrishnan at Pennsylvania State University.

We don't currently know what the real risks are. Thwaites was the last part of Antarctica's coastline to be mapped in detail, in 1940. Scientists first set foot there in the late 1950s, followed by a hiatus until research ships visited in the 1980s and 1990s. It wasn't until 2004 that planes with ice-penetrating radar gave us our first real idea of how thick the glacier is, vital for knowing how it could respond to a changing climate. The five-year International Thwaites Glacier Collaboration, a $50 million UK-US initiative that started in 2018 is now harvesting data from above, below and around the glacier. But as with all these huge climate uncertainties, the clearest way to mitigate the risk is clear: to stop the cause of its melting at source. ▮

# EXTREME WEATHER

Heatwaves might be the most obvious climatic consequence of global warming, but they are far from the only one. From hurricanes to flooding, the effect of extreme weather events is already being felt across the world – and that's only going to increase.



SOURCE: CARBON BRIEF

Studies have pinpointed links between climate change and many extreme weather events worldwide

EXTREME weather is nothing new – storms and floods have been costing human lives since time immemorial. But in recent years, something has been stirring. In 2020 alone there were record-breaking bushfires in Australia and California. Extreme flooding hit many parts of the world, from China and Bangladesh to West Africa.

The US hurricane season, meanwhile, saw 30 named tropical cyclones, the highest number recorded and more than double the long-term average of 12 named storms. These included 13 hurricanes, against a long-term average of six. In the US Midwest region a derecho storm – a large system of fast-moving thunderstorms that can whip up very strong winds – caused billions of dollars of crop damage. Adam Smith at the US National Oceanic and Atmospheric Administration (NOAA) says 2020 may bring the biggest financial losses yet attributable to extreme events.

That's partly because more people in the US now live near forests and coastlines, but also undeniably because of climate change, he says. Climate scientists were long wary of making that explicit connection. Weather patterns are naturally cyclical. Before 2020, the greatest number of named tropical storms in the US came in 2005, among them Hurricane Katrina, which devastated parts of New Orleans. The La Niña climate phenomenon, the flip of El Niña, is known to brew up more storms in the Atlantic basin, and undoubtedly played a part in both record years. But 2020 was the fifth year in a row with above-average hurricane intensity, and that is unusual.

In general, what we are seeing is in line with model projections, says Peter Stott at the Met Office Hadley Centre in the UK. A warmer atmosphere has more energy in it, and basic physics says the amount of water vapour in the lower atmosphere rises by about 7 per cent for every 1°C of warming, exactly what is happening. Better models are now allowing us to see what that means for the future.

For instance, they suggest that the amount of rain falling in summer storms – the kind that cause flash floods – could increase by about 14 per cent for every degree of warming. That would mean about a 60 per cent rise if the world warmed by 4°C. "That's a very substantial increase in the amount of rain falling in heavy summer convective situations, which is well outside the envelope of what we're adapted to," says ›

ROSCHETZKY/ISTOCK

“Extreme weather doesn’t always come in the form of single events”

Stott. They also predict stronger tropical cyclones that are also slower-moving, dumping more rain in one place and causing more damage.

Extreme weather doesn’t always come in the form of single events. Jennifer Francis, an atmospheric scientist at Rutgers University in New Brunswick, New Jersey, has shown that the rapid warming in the Arctic is making the jet stream – the high-level river of air that snakes around the northern hemisphere – more wavy. A warmer Arctic has made the north-south air temperature contrast smaller, weakening the jet stream, and making it more prone to being deflected by obstacles in its path, such as mountains or anomalies in ocean temperatures.

Places in north-west Europe are beginning to feel the full impact of this wavy jet stream, thanks to an unusual cool patch of water in the North Atlantic, probably created by excess melting of the Greenland ice sheet. If the jet stream skirts around the bottom of this patch, it can align itself in a south-west to north-east direction, placing areas of the UK and Ireland right in its crosshairs. Once jammed in place, it can fire storm after storm at the same locations, a phenomenon seen in recent winters. The record-breaking floods of July 2021 in Germany and the Low Countries, which followed some places seeing almost twice their monthly rainfall in just two days, were also caused by a low-pressure weather system trapped almost to a standstill by a kink in the jet stream.

On the other side of the North Atlantic, meanwhile, an unusually warm patch of ocean off the west coast of the US can add an extra winter kink to this high-level wind. Under these circumstances, the north-west of the country gets caught under freezing polar air to the jet stream’s north, while the south and east coast swelters in unseasonably warm tropical air. Where the two air masses meet, powerful tornadoes can spin up.

We still can’t pin any single extreme weather event on our greenhouse gas emissions, but in recent years, researchers have become far better at estimating how much more probable any given “natural” disaster was made by human-caused global warming. This “extreme event attribution” involves comparing real observations of weather events with computer simulations of a world with and without the roughly 1°C hike in temperatures we have caused so far.

Run the simulations thousands of times and you can calculate the odds of the event occurring in both scenarios. Such an approach tells us, for example, that the drought conditions responsible for the 2020 Australian bush fires were made at least 30 per cent more likely by climate change, and that human-induced warming made the Siberian heatwave 600 times more likely. ■

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See the interview on page 47 for more on climate attribution studies

# SPREADING LIKE WILDFIRES

**Extreme heat unleashes one of humankind's oldest enemies: fire. Wildfires are increasing in range and intensity as the climate changes. To gain control, local knowledge is key.**

FOOSION/ISTOCK

Wildfire threatens more human habitations as we encroach further into nature's space

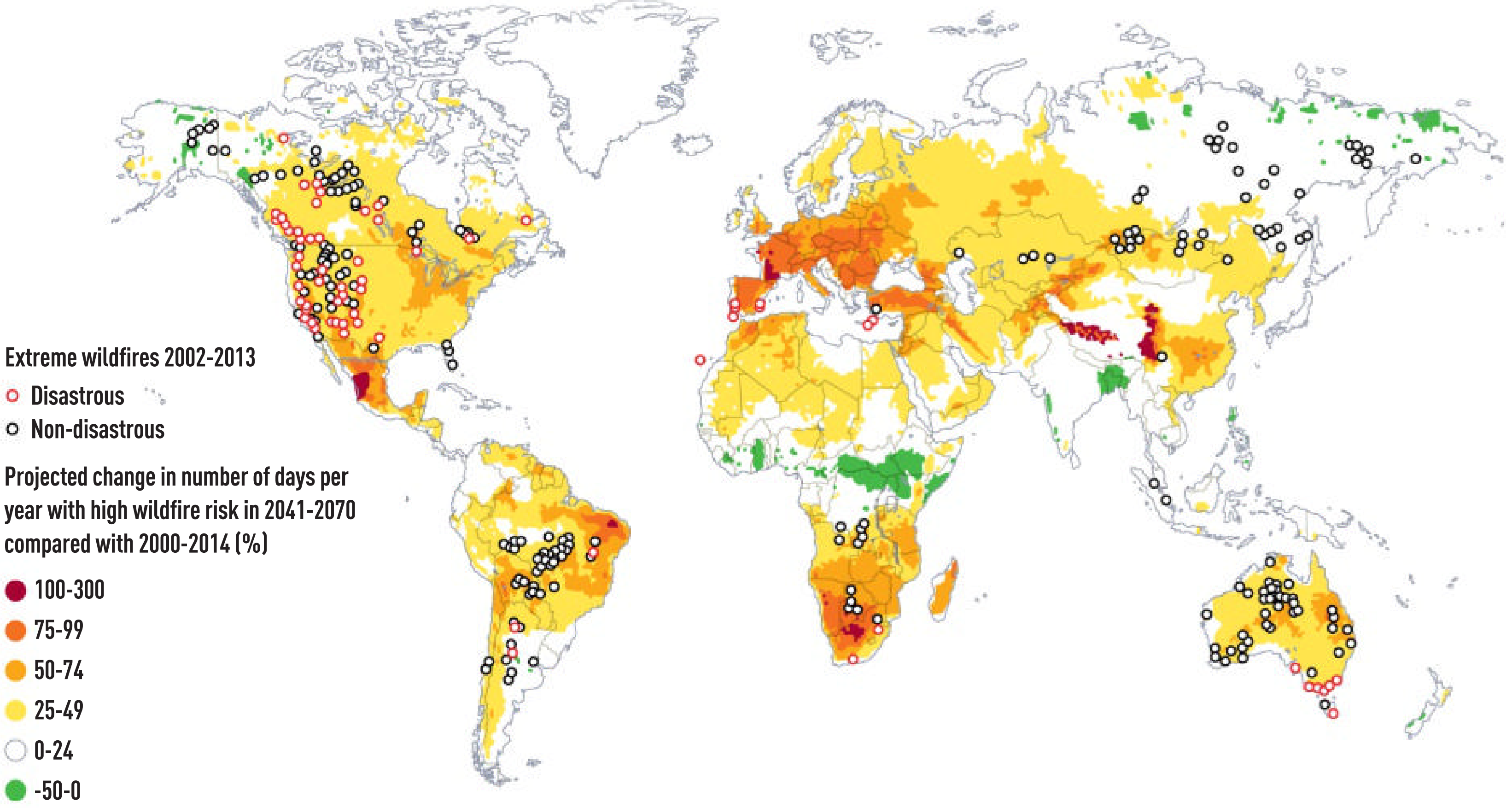
"I LIVE in a city that can be completely destroyed by fire," says David Bowman at the University of Tasmania. Fifty years ago, the Tasmanian capital, Hobart, came within a whisker of being burned to the ground as flames raked in from the surrounding hills. Some 3000 buildings and 80 bridges were destroyed; more than 60 people died.

When wildfires hit the news, they tend to be in tinderbox lands such as south-eastern Australia and the western US. Both were in the headlines in 2020. In California, pictures of orange skies mid-year looked like a smoking hellscape from the film *Blade Runner 2049*. The images of the huge wildfires there, and in Australia earlier in the year, became perhaps as emblematic of 2020 as those of people wearing face masks. Less well-known is that 2020 was a record-breaking year for Arctic wildfires – after 2019 was, too.

Long before our species existed, natural wildfires caused by lightning or lava were shaping the planet. Globally, wildfires may in fact be becoming less frequent owing to changes in rainfall patterns. But their range is spreading, and they are becoming more intense and destructive when they do occur. As weather extremes become more extreme, wet periods that promote vegetation growth are followed by heat waves and droughts that make landscapes ready to take flame.

In California alone, forest fires burned 4.2 million hectares between 1984 and 2015, almost double the area expected without global warming – with huge additional costs in destroyed infrastructure, degraded ecosystems, smoke-related disease and loss of life. Globally, carbon dioxide emissions from wildfires equal half those from burning fossil fuel, a warming effect compounded by heat-absorbing black-carbon aerosols they release. The increasing wildfire frequency in the Arctic also ›

Disastrous wildfires with substantial economic, political or social impacts are currently concentrated in a few areas, notably western North America and southern Australia. As the climate warms, other areas are expected to become more at risk


Extreme wildfires 2002-2013
○ Disastrous
○ Non-disastrous
Projected change in number of days per year with high wildfire risk in 2041-2070 compared with 2000-2014 (%)
● 100-300
● 75-99
● 50-74
● 25-49
○ 0-24
● -50-0

SOURCE: BOWMAN ET AL. DOI:10.1038/S41559-016-0058

risks releasing carbon stored in permafrost.

In 2017, Bowman's team revealed the first global picture of human exposure to wildfires, present and future. The greatest risk, unsurprisingly, occurs where human habitation encroaches into flammable landscapes in Australia and the US. Despite its similar climate and vegetation, southern Europe historically has had fewer extreme fires. But as people migrate from the countryside into cities, creating urban sprawl and leaving fallow land that was once intensively worked, that picture is changing – a point underscored by deadly wildfires that engulfed central Portugal in 2017.

The study suggests susceptible landscapes could see an increase of between 20 and 50 per cent in the number of fire weather days, with the worst-affected areas being on the Australian east coast, including Brisbane, and across the Mediterranean (see map, above).

Coping with these trends will mean changing how we deal with wildfires. Modern Western wildfire control methods lean heavily on pre-emptive burning, almost always involving big fires set at the start of the dry season to reduce the amount of combustible material. But as landscapes get drier, pre-emptive burning can itself get out of control: in 2012, a fire set by the Colorado State Forest Service in Lower North Fork, south-west of Denver, destroyed more than 20 homes and killed three people. Annual burning also favours the growth of flammable grasses adapted to the environment, an expanding problem as more people move into highly combustible areas and the risk of arson and accidental wildfires increases.

Patch-burning methods, used for example by Aboriginal Australians who have long lived with wildfire risk, may be a better strategy. By setting smaller scale, less intense fires, the amount of flammable grass can be reduced while sparing the tree canopy, producing a fine mosaic of burned and unburned patches. Bowman's work involves observing Aboriginal practices and translating them into a Western scientific vocabulary of distinct "fire regimes". These are characterised by measurable factors, such as what type of vegetation burns, whether the fire flames or smoulders, how fast a fire spreads, when and how regularly fires are lit, how big they are, patchiness, and impact on vegetation and soils.

It's a case of hasten slowly, he says. The patch-burning approach must be modified to account for climate change and suburban sprawl into bushland, for example. "Tasmania has a very fire-sensitive ecology and we don't want it to go up in flames," he says. There's no universal algorithm for dealing with wildfires – but drawing on our deep, collective heritage of proactively managing fire may be the best way to damp them down. ▮

INTERVIEW

# “CLIMATE CHANGE IS HAPPENING RIGHT NOW”

**Friederike Otto’s work means we are now able to assess how much more likely individual heatwaves, droughts and hurricanes are made by global warming – evidence that could soon be used against those most responsible for it.**

**How do you describe your job to people?**
I’m trying to answer the question of whether, and to what extent, human-caused climate change altered the likelihood and intensity of recent extreme weather events. The data-processing aspect of that is a very small part of my work. Most of my day-to-day work is thinking about the most appropriate data sources to use for these kinds of studies, or which models should be used, or how we can test the models better to see whether they are able to reliably simulate the weather event.

**Does having more extreme weather events as the planet warms make attribution easier or harder?**
The main difficulty is in whether we have models that really represent the processes behind extreme weather events. For example, do we have models that are able to simulate strong enough hurricanes in the first place? That doesn’t really change with increasing temperatures. On the other hand, the signal of human-caused climate change gets bigger with increasing temperatures, so it is getting easier to disentangle it from the noise.

**What has attribution achieved so far, and what’s next?**
I think the impact so far is really in raising awareness of the fact that climate change is happening right now, and that wherever you live in the world, there are damages from extreme events that you would not have had without climate change.

On what comes next, one of the things I’ve learned relatively recently is that it would be better not just to say the weather today has changed because of climate change, but also to say something about what that means in the future. So now we have a world that is 1°C warmer than in pre-industrial times. How would weather patterns change in a 2°C-warmer world?

We do not only want to understand what climate change means right now, but what we will need to adapt to. Which are the types of events and areas of the world where climate change is a real game changer, so that we have to completely alter how we deal with the impacts of such events? With limited resources, it is important to understand where to best focus them.

**There’s talk about now using attribution in legal cases in which people claim for damages against fossil fuel companies or governments.**
The legal community is realising that this is now a possibility. In many older climate litigation cases, the reason for not admitting evidence that humanity’s greenhouse gas emissions are to blame for extreme weather events and the damage they cause, was that you can’t say the chain of causality is complete. We

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HORST FRIEDRICHS/ALAMY STOCK PHOTO

## PROFILE FRIEDERIKE OTTO

**Friederike Otto is a climate scientist at the University of Oxford and co-founder of the World Weather Attribution project**

are not far off seeing successful cases using that kind of argument – in one, two or three years.

The way society sees climate change has changed too, and judges are a part of society. It would be very strange if that shift in public perception would not also filter through to the courts; that understanding that climate change and the damages it causes are real.

→ See page 72 for more on climate change and the law

### What difficulties might there be in using climate attribution studies in court?

At the moment, especially with heatwaves, we can only give a lower bound: we can say OK, climate change made it at least 30 per cent more likely. It would be better to be able to also at least quantify the upper bound. So that is a problem. If you want to quantify damages, and if you want to understand the extent of the adaptation measures you are going to need to put in place, such as higher flood defences, then you need more detail.

### Most attribution studies have been done for events in the developed world. Is that a problem?

We absolutely need to redress the balance. On the one hand, it would help us to understand what climate change means globally. But more than that, if we really want to adapt to climate change, understanding the extreme cold snaps in the US, for example, might not be the most important thing. It might be more important to understand the droughts we see in East Africa. At the moment, there is no evidence that climate change is causing migration from eastern Africa, but it is a question we must address. We can't just ignore parts of the world and think it doesn't affect the rest of us.

### How optimistic are you that we are going to get a handle on reducing emissions globally?

I'm very optimistic we will have a world we can still live in. One of the main reasons for hope is what has happened in the past years in terms of how the conversation has changed on climate change. For most people in my generation, and definitely the people in the younger generations, climate change is something that is important and there's no question that it's something that needs to be tackled. ■

PHOTOMONTAGE: ANDREY POLIVANOV/CHANTAWUTE CHIMWAN/SHUTTERSTOCK

# THE CHANGING OCEANS

**More than 90 per cent of the excess heat caused by our carbon emissions is stored in Earth's oceans. That is having many knock-on effects – on sea level, on weather patterns and on the fate of much marine life.**

OCEANS cover 70 per cent of Earth's surface. Water absorbs heat more efficiently than air, so ocean temperatures have been rising more slowly than land temperatures. But they are rising. Surface waters have warmed first and fastest, but heat is now penetrating deeper. Ocean heat content was at a record level in 2020, with areas in temperate zones of the Atlantic and Pacific and towards the poles showing the biggest increases (see graphic, page 50). Over the past 35 years, the number of marine heatwave days has doubled. With half a degree more warming, this tally is expected to increase a further eightfold.

Perhaps the most headline-grabbing effect is coral bleaching in places like Australia's Great Barrier Reef. This process occurs when coral is exposed to a temperature above what it can stand for more than a month. This causes it to expel algae that live inside it and provide it with food, leaving it ghostly white and with no source of energy. A percentage of coral don't › reacquire their algae and die. Coral bleaching has always resulted from natural cyclical temperature variations, for example during warming El Niño phases. But since 1980, the gap between bleaching events has on average halved. In an El Niño-exacerbated phase from 2014 to 2017, some 70 per cent of the world's corals are thought to have been damaged.

Coastal ecosystems such as seagrass, salt marshes and mangroves are also suffering. Kelp, coral and seagrass are "ecosystem engineers", building physical structures that create habitats for other life – coral reefs support over a million species, for example – and also provide food and protection to people.

Acidification caused by dissolved carbon dioxide will also affect a wide range of organisms, from fish to algae. It also affects the ability of organisms such as molluscs to produce calcium carbonate to make their protective shells. The oceans absorb about 30 per cent of our emissions and their pH has fallen by 0.1 units since pre-industrial times – a change unprecedented in the past 65 million years. One model projects that catches of marine fish will decrease by 1.5 million tonnes a year under 1.5°C warming.

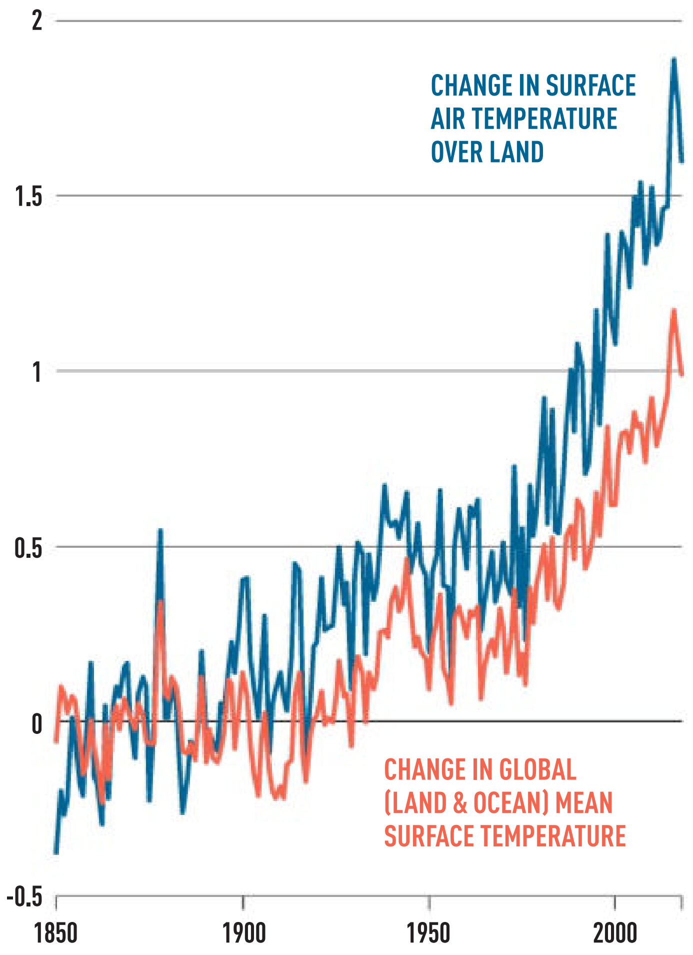
↓ The next section has more on climate change and biodiversity

Many of the effects of ocean warming are less visible and longer-term, however. Warming waters expand, a major contributor to sea-level rise that has averaged over 3 millimetres a year since precise measurements began in 1993, with that trend accelerating (see graphic).

Meanwhile throughout the oceans, powerful currents push water the length, breadth and depth of the various interconnected basins. One of the most studied is the Atlantic ocean conveyor belt, also known as the Atlantic meridional overturning circulation or AMOC. From the tropical Atlantic off the coast of South America, warm surface water flows north towards

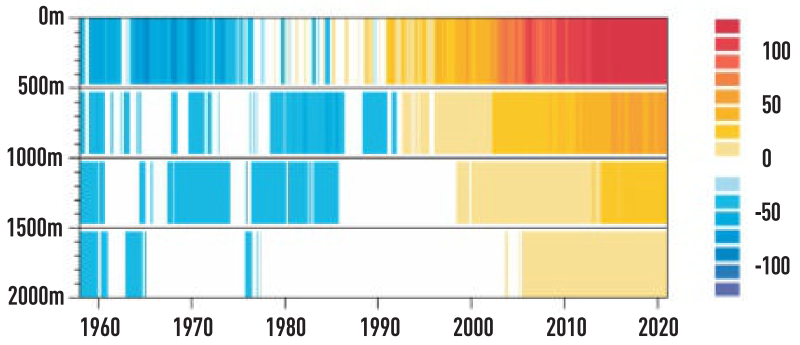
**Earth's land surface is heating faster than its oceans, but ocean heating is spreading in extent and depth penetration (bottom)**

Temperature change relative to 1850-1900 (°C)

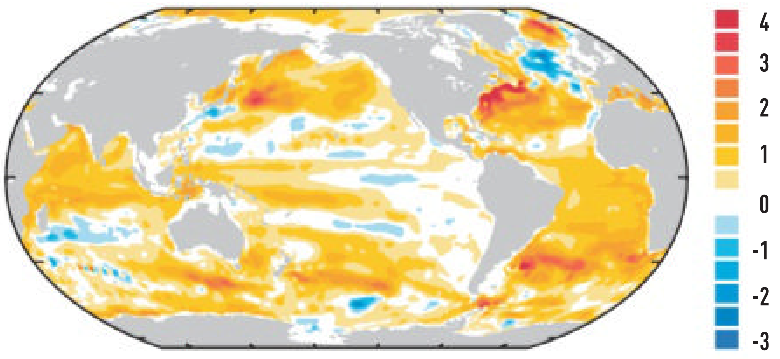


SOURCE: IPCC, CLIMATE CHANGE AND LAND SPECIAL REPORT

Variation in ocean heat content at different depths relative to 1981-2010 baseline (zettajoules)



Variation in ocean heat content in 2020 to a depth of 2000 metres relative to 1981-2010 baseline (gigajoules per $m^2$)



SOURCE: CHENG ET AL., DOI.ORG/F5KJ

Greenland and western Europe, bringing with it an uncharacteristically warm climate, carried by the Gulf Stream.

The water becomes saltier as it evaporates, and it cools and sinks as it moves north towards the Norwegian and Greenland seas. From there, it makes its way back south at depth (see map, below right). In 1961, oceanographer Henry Stommel showed that, in theory, these currents could exist in one of two states, with water flowing in opposite directions depending on the balance of temperature and density.

At the time, this was just a curiosity. But in the 1980s, climate scientists warned that fresh water pouring into the north Atlantic from Arctic ice melt would slow the natural sinking of AMOC waters, putting a brake on one end of the conveyor belt. Just that seems to have happened between 110,000 and 12,000 years ago, when much of northern Eurasia and North America were covered in ice. Battalions of icebergs periodically broke off and went marauding around the Atlantic. Spiked by fresh water, the AMOC weakened.

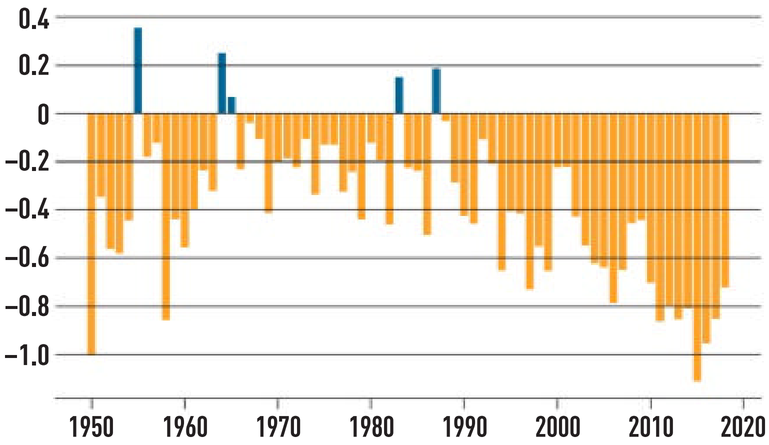
"Because there were similarities between what happened then and what we were predicting in the future, that caused concern that the AMOC could weaken in the future," says David Thornalley at University College London. The notion was made famous with the 2004 disaster movie *The Day After Tomorrow*, in which the AMOC shuts down in a matter of days, triggering a snap ice age across Eurasia and North America and ocean-spanning mega-storms.

In reality, a total collapse would probably take decades or a century – but it would have consequences right across the globe. A weaker AMOC would shift water around the Atlantic, leading to extremely rapid sea level rise along the US east coast – adding 15 to 21 centimetres at New York City by 2100 according to one estimate. This would bring more severe flooding whenever storms hit. A weaker AMOC might reduce the deep ocean's ability to store heat, boosting atmospheric warming. "The north Atlantic might get colder, but it

›

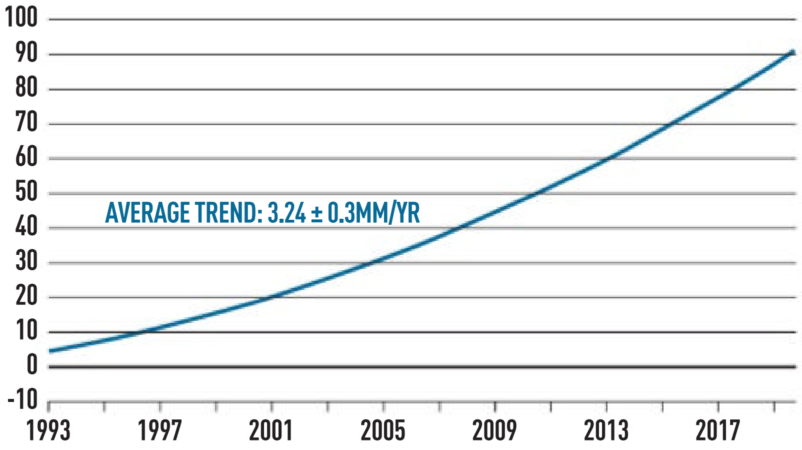
**Worldwide loss of glacier mass has accelerated in recent decades, helping to propel a global rise in sea level of almost 10 centimetres, and possibly changing ocean circulation (bottom)**

Change in global glacier mass (tonnes per m$^2$)



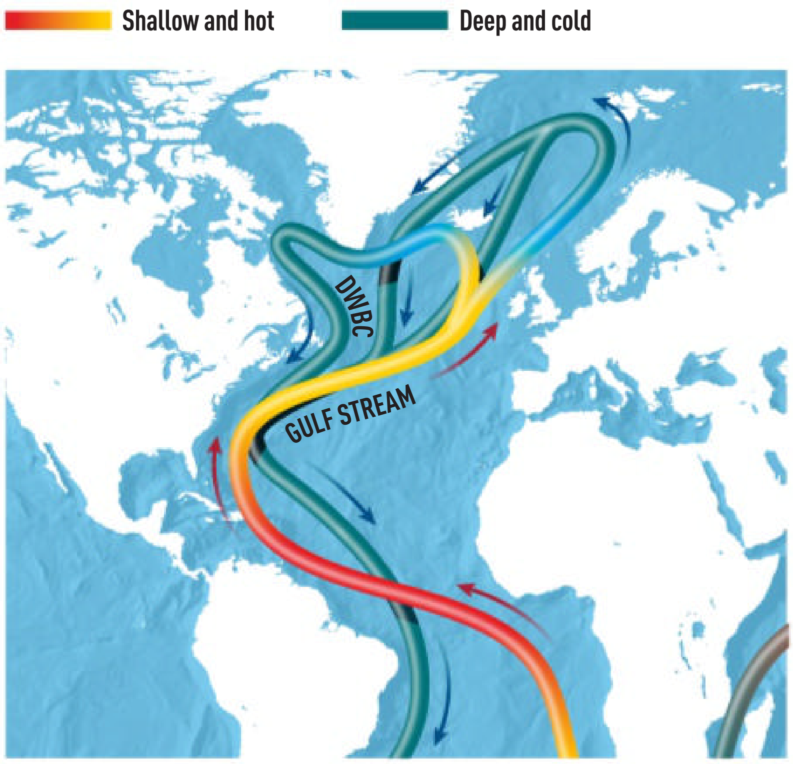
SOURCE: WMO STATEMENT ON THE STATE OF THE GLOBAL CLIMATE IN 2018

Global mean sea level rise (mm)



SOURCE: WMO 2019 REPORT

**The 'Atlantic conveyor belt' involves the warm surface waters of the Gulf Stream cooling and sinking as they move north, then flowing back south in the deep western boundary current (DWBC). There are some signs the effects of Arctic ice melt are causing it to slow**



means everyone else is getting a bit warmer," says Thornalley. Europe might become hotter and drier. A weakened AMOC could even shift monsoon rains hundreds or thousands of kilometres north or south, leaving many regions in Central America, Africa and southern Asia that depend on them parched.

So what is actually happening? Detailed measurements starting in 2004 have shown that the AMOC is highly variable from season to season. But while there was a warming trend in most parts of the ocean since the beginning of the 20th century, in the north Atlantic, a blob-shaped region has cooled, particularly since 1970. That blob is also visible in maps of global temperature anomalies today (see map, page 50). Climate models suggest that such a cool spot is a sign of a weak AMOC. What's more, further studies using records contained in tree rings, marine sediments, ice cores and corals to stretch temperature measurements back to AD 900 revealed no previous signs of a north Atlantic cool spot, suggesting that the AMOC slowdown since 1970 is an unprecedented event in the past millennium.

In recent years, Europe has been hit by scorching summer heatwaves that seem to be linked to the cold spot in the north Atlantic. A spate of extremely cold winters and snowstorms in the eastern US in recent years might also be linked to the current's weakening as the cold patch in the north Atlantic affects the atmospheric jet streams over North America.

The case that the AMOC is getting weaker, and is starting to affect weather patterns, looks quite strong. That's a long way from saying we're close to a more dramatic collapse. The core problem with predicting that eventuality is that even after decades of study, it is unclear how big a "push" is needed for collapse. As the AMOC slows down, it comes closer and closer to a theoretical tipping point that would lead to its collapse, but we still don't know how close to that threshold we are. ▮

**Wildfires and polar ice melting are two climate-related factors imperilling species around the world**

CAPSTOC/ISTOCK

RIXIPIX/ISTOCK

**Global warming is hitting habitats and species already under pressure from human activities. By understanding how the problems of climate change and biodiversity loss are linked, we can take actions that will help nature help us.**

# CLIMATE CHANGE AND BIODIVERSITY

FOR biodiversity, climate change is, in military jargon, a threat multiplier. Global warming is having an impact on species and ecosystems that in many cases are already under strain from pollution, or through carving up their habitat for farmland and roads.

The effects of the warming we are experiencing now are already in some cases dramatic. In the Arctic, the loss of more and more sea ice each summer is affecting many animals, from walruses to polar bears. Polar inhabitants have nowhere colder to go, but many creatures elsewhere are already moving to stay in their comfort zone. Marine species, including mammals, birds, fish and plankton, have shifted their ranges by hundreds of kilometres.

Other effects are more subtle. Oceanic low-oxygen zones are expanding because oxygen is less soluble in warm water. This is forcing species such as blue sharks to stay closer to the surface, making them more likely to be caught by fishing boats.

Rising sea levels, meanwhile, could wipe out species as low-lying islands are inundated. Mainland species are also at risk, such as the few hundred Bengal tigers in the Sundarbans, a network of mangrove forests along the coast of Bangladesh and north-east India. The effects of habitat destruction and rising water levels mean there will probably be no suitable habitat left there for these tigers by 2070.

Not all threats are as gradual as the melting of ice caps and the rising of sea levels. Hurricane Dorian, one of the strongest Atlantic storms ever recorded, may have wiped out several bird species in the Bahamas, including the Bahama nuthatch and the Abaco parrot, when it hit the islands in 2019. Warming-fuelled wildfires could also take out species with smaller populations. In 2015, fires in Western Australia burned much of the remaining habitat of Gilbert's potoroo, one of the world's rarest mammals.

A warming world isn't bad news for all species. Some, especially small, highly adaptable and fast-reproducing ones, are thriving. But these tend to be things we regard as weeds, pests or unwanted invaders, such as mosquitoes, bark beetles and jellyfish.

So far, few species have been conclusively driven to extinction by climate change. The most clear-cut case is the loss of the Bramble Cay melomys, *Melomys rubicola*. This rat-like rodent was found only on its namesake island home, a tiny, low-lying Australian cay on the northern edge of the Great Barrier Reef. It died out some time after 2009 as rising sea levels led to the island being inundated during storms. Climate change is also thought to have aided the spread of a fungal disease called chytridiomycosis that has wiped out nearly 100 amphibian species.

So far, Earth hasn't warmed much beyond the bounds of natural variations experienced over the ›

“We are heading into the era of serious global warming with wildlife already devastated”

past few million years. But many slower feedbacks, such as the melting of permafrost and the Antarctic ice sheet, have barely begun to kick in. We are heading into that with wildlife already devastated by our activities. Humans have altered three-quarters of all land and two-thirds of the oceans, according to a major 2019 report on biodiversity. More than a third of land and three-quarters of freshwater resources are devoted to crops or livestock.

The “ecosystem services” that nature provides for free are worth trillions of dollars and underpin many livelihoods. For instance, hundreds of millions of people depend on coral reefs, much affected by warming oceans, for tourism and the fish stocks they support, says Ove Hoegh-Guldberg at the University of Queensland in Australia. “This is an issue of people as much as it is about ecosystems and biodiversity,” he says.

By intruding into wild areas and exploiting wildlife, we are also giving pathogens such as the virus causing the covid-19 pandemic more chances to make the jump into humans or domesticated animals. Warming is generally expected to make matters worse, for example by allowing disease-carrying tropical mosquitoes to spread more widely.

One recent study looked at the effect of future climate change on 80,000 species in 35 of the most wildlife-rich areas, including the Amazon rainforest and the Galapagos Islands. With warming of 5°C by around the 2080s, half of these species would no longer be able to survive in these areas.

One issue with studies of this kind is that they assume species can’t survive outside their current climatic range. Many are already evolving and adapting as their habitats warm. In Finland, for instance, tawny owls are turning brown as snow cover declines. There is a limit to what evolution can achieve, though, especially in species that reproduce slowly. Not only is the climate starting to change much faster than it has during the past few million years, but many species have suffered huge losses of genetic diversity as their numbers have declined. This makes it much harder to adapt to a changing environment.

To get a better picture of how wildlife will cope, in a recent study John Wiens at the University of Arizona and his colleagues focused on about 500 plants and animals worldwide, looking at where they have already become locally extinct as the world has warmed. The results suggest that what matters most is the maximum annual temperature, not mean temperature. “The most straightforward explanation is that it just literally gets too hot and they die,” he says.

The conclusions are similar to those of many other studies, suggesting that about a third of terrestrial species could be lost altogether by 2070. “That could be cut in half by following the Paris Agreement and keeping temperature below an increase of about 1.5°C,” says Wiens.

As dire as these forecasts are, they may underestimate future extinction risk. “There could be a lot more extinctions caused by things like sea level rise,” says Wiens. It can take hundreds or even thousands of years for the full effects of changes such as habitat loss to play out – a phenomenon called extinction debt. In Europe, for instance, the number of extinctions happening today is more strongly linked to what happened a century ago than to current events.

Some threats to biodiversity can’t be forecast with any certainty. For instance, people forced from their homes by disasters or conflict can have an impact, rapidly deforesting vast areas and greatly reducing wildlife populations. Floods and storms displaced 15 million people in 2018 alone, and these numbers will rise as extreme weather becomes more extreme.

The combined effect of all these threats can multiply and be worse than any one alone. “For example, corals recover from bleaching episodes more slowly when they suffer stress from pollution, or damage from coastal development or poorly regulated sport or commercial activities,” says Sandra Díaz at the National University of Córdoba in Argentina. Similarly, in tropical forests, unusually hot and dry years, combined with the creation of roads, greatly increase the chances of destructive fires, she says. “Our best calculations and projections do not incorporate all the possible cascading and non-linear effects. They are on the conservative side.”

The benefits of restoring and expanding wild areas could also be greater than we think. In general, areas that are rich in wildlife also store lots of carbon, says Eric Dinerstein of the environmental organisation RESOLVE in Washington DC. His team has mapped out what additional areas around the world, for example in the Amazon basin or on Madagascar and Borneo, need to be protected to both help the greatest number of species and maximise carbon storage.

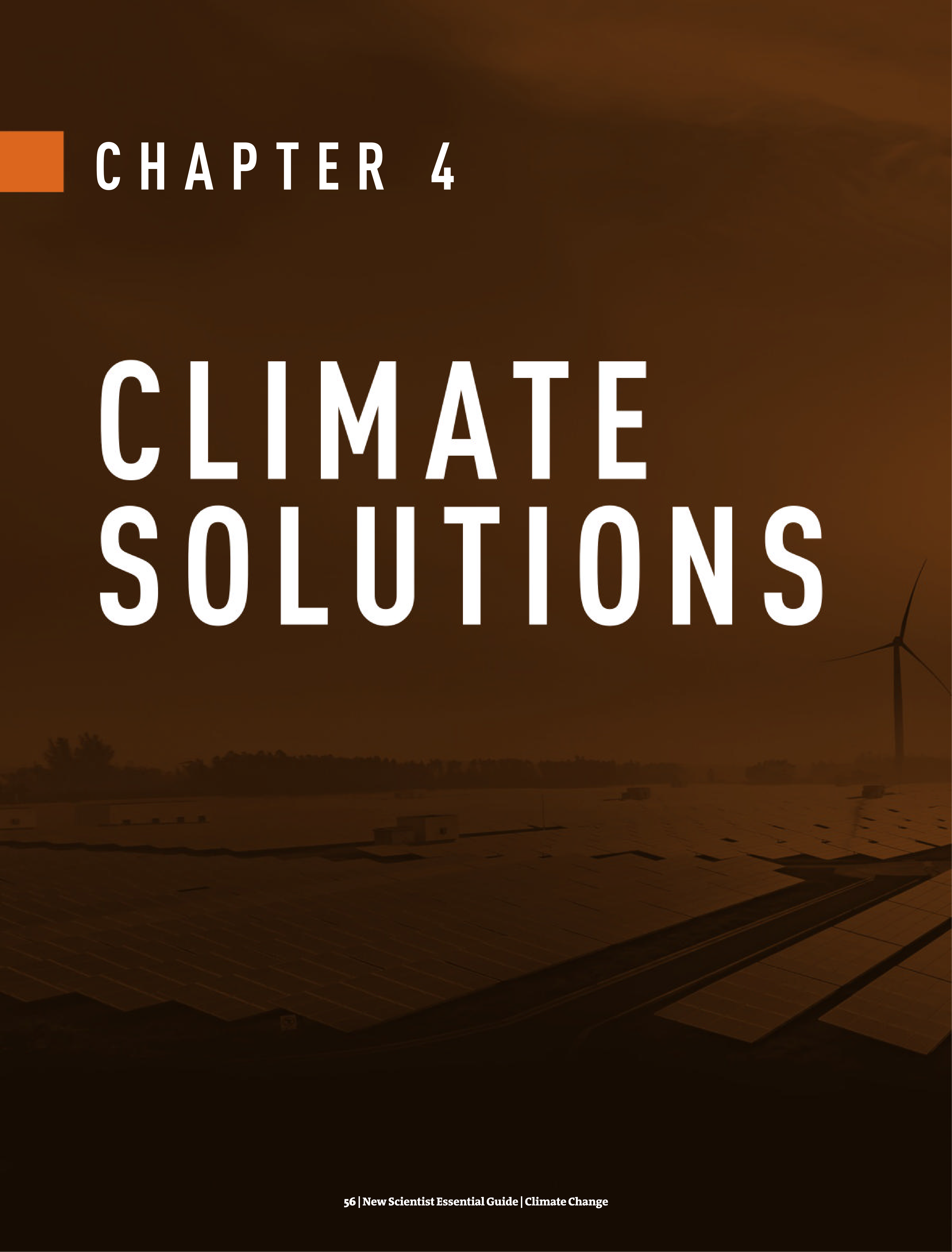
There is growing awareness that climate change and biodiversity are inextricably linked, and that we need joined-up policies to tackle both. “The two are so interdependent and the solutions are interdependent,” says Dinerstein. “We can’t save biodiversity without staying below 1.5 degrees, and we can’t stay below 1.5 degrees without saving biodiversity.” ▮

## THE HUMAN IMPACT

The changes to the Earth system from climate change, both present and future, matter because they impact human well-being. Changes at sea and on land will have a significant impact on food security: warming is expected to reduce the productivity of livestock farming, fisheries and aquaculture. Despite hopes that increased warmth and carbon dioxide could make terrestrial crop agriculture more productive, real-world yields, particularly in the tropics, appear to be falling as the climate warms. Faster growth under conditions of higher $CO_2$ will also lead to lower levels of some nutrients in crops.

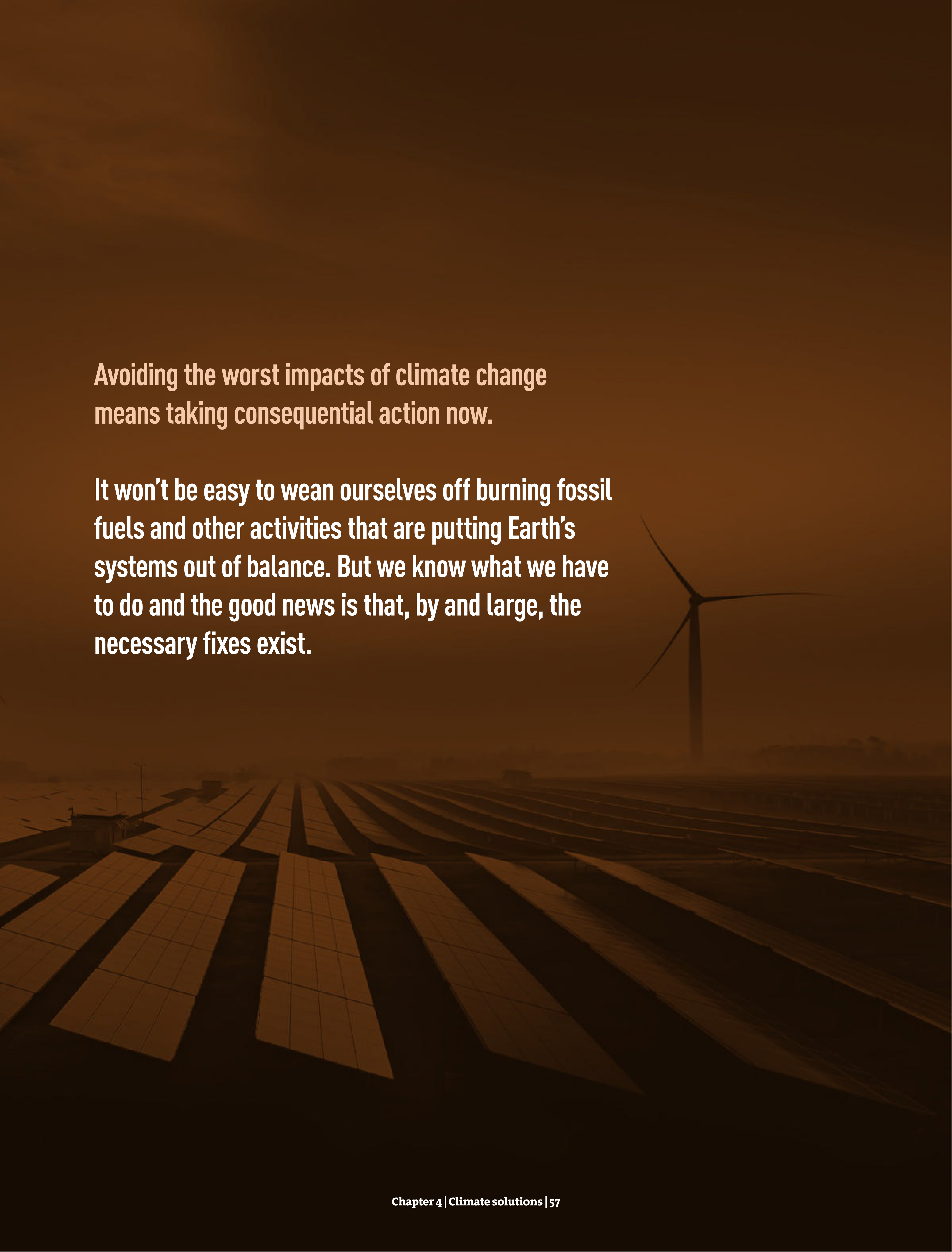
An extra 95,000 children a year are projected to die of malnutrition in a warmer world, and 48,000 more from diarrhoea, according to the World Health Organization. Mosquitoes carrying malaria, dengue fever, chikungunya, yellow fever and Zika virus will spread, with 60,000 extra deaths expected from malaria. Europe and North America can expect to see more cases of West Nile virus and Lyme disease.

All these developments spell economic trouble. The IPCC calls climate change a “poverty multiplier”, meaning that more people get dragged into poverty and people who are already poor get even poorer. All told, global warming of 1.5°C could plunge more than 100 million people into extreme poverty. Migration and conflict are expected to increase as a result, although making precise forecasts of this is all but impossible. And it isn’t just developing economies that will suffer: each degree of warming, for example, is expected to damage the US economy to the tune of 1.2 per cent of GDP per year. Taking action to mitigate climate change is a matter of hard, rational self-interest.



## CHAPTER 4

# CLIMATE SOLUTIONS



Avoiding the worst impacts of climate change means taking consequential action now.

It won't be easy to wean ourselves off burning fossil fuels and other activities that are putting Earth's systems out of balance. But we know what we have to do and the good news is that, by and large, the necessary fixes exist.

# SEVEN CHALLENGES TO SAVE THE CLIMATE

**Progress so far on reducing the rate at which our carbon emissions are rising – and in some cases beginning to reduce them – has been largely down to decarbonising electricity supplies. But that is just the first of some increasingly high hurdles on the route to net-zero emissions.**

RIGHT: JENSON/ISTOCK
PREVIOUS PAGE: HUANGYIFEI/ISTOCK

## *CHALLENGE 1: ELECTRICITY GENERATION*

IN THE past few years, the transition to renewable energy has begun in earnest, driven by rapid progress in ramping up wind and solar electricity generation. Something like a quarter of the world's electricity needs, making up more than 10 per cent of our total energy consumption, is already covered by modern renewable sources, meaning anything but the traditional burning of biomass such as wood and dung.

Most pathways to limit warming to 1.5°C, the aspiration set out in the 2015 Paris climate agreement, require at least 50 per cent (and preferably much more) of the world's energy needs to come from renewables by 2050. That means the almost complete decarbonisation of electricity generation – 100 per cent renewable electricity generation.

↓
See page 64 for more on 100 per cent renewable electricity

The winning scenarios, set out in a 2018 IPCC report, rely heavily on wind and solar, but also hydropower, geothermal energy and biofuels. Most pathways also require us to use nuclear energy more. In some scenarios, fossil fuels can remain in the mix, but must be defanged by using carbon capture and storage (CCS) – a technology to neutralise carbon emissions that exists currently only on small scales (see Challenge 4, below). Coal, which produces more carbon per unit of energy than any other fossil fuel, must cover at most 13 per cent of our overall energy needs, and preferably zero. ›

←
Chapter 2 has the lowdown on climate politics and goals

The transition still isn't happening fast enough, but nobody doubts that it is eminently doable, given the right nudges from policy-makers and financiers. These include ending both direct and hidden subsidies for fossil fuels, and imposing a form of carbon pricing to reflect the environmental damage that fossil fuels cause. Whether we will get those things to help us complete this challenge is another question entirely.

### CHALLENGE 2:TRANSPORT

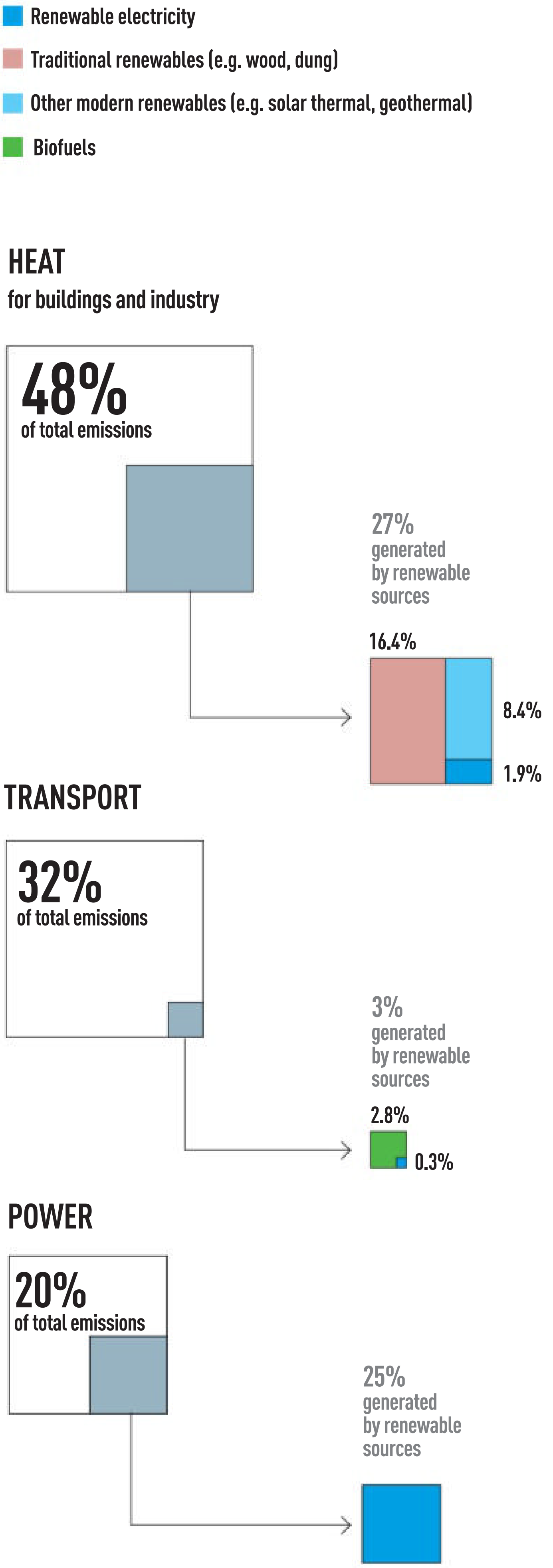
Decarbonising electricity isn't enough to reach net zero: at the same time, we must ensure that other kinds of energy-consuming activities, currently powered by dirty fuels, convert to clean electricity or otherwise clean up their act. More than 90 per cent of transport is powered by oil, in the form of petrol, diesel and aviation fuel, and just 3 per cent of transport-related energy comes from renewables. Transport accounts for something like a quarter of the world's energy-related carbon dioxide emissions, and its contribution is growing by about 2.5 per cent a year. Recognising the scale of the challenge, most 1.5-degree pathways call for only a 30 per cent reduction in transport-related emissions by 2030.

Besides switching to electric vehicles (powered, of course, by renewables), reaching these goals means improving fuel efficiency and finding sustainable alternatives to hydrocarbon fuels, including in aviation. Together, these can deliver 80 per cent of the required cuts. Hydrogen-powered transport is also being bigged up – but questions remain there about the viability of the technology, or indeed how green it is (see page 67). The rest will have to be done through personal sacrifice: choosing buses and trains over cars and planes, car-sharing and even avoiding travel altogether – unless you go on foot or by bike.

### CHALLENGE 3: BUILDINGS

Homes, offices, shops and other buildings are responsible for something like a quarter of the world's energy-related emissions. Most of that is indirect consumption, via electricity used for lighting, heating, cooling, elevators, office equipment and other energy-sapping services such as kettles and servers. The massive expansion of zero-carbon

Heating is the largest source of non-agricultural carbon emissions, followed by transport and power generation – with fossil fuels dominating all sectors



SOURCE: RENEWABLES 2018 GLOBAL STATUS REPORT electricity will give us a head start to this challenge.

But a third of building-related carbon emissions come directly from burning fossil fuels, mostly gas for heating and cooking. Because of the difficulties in decarbonising transport, we must give it our all here, reducing emissions by 80 to 90 per cent by 2050. Our strategy must include switching to energy-efficient lighting to reduce electricity consumption, installing state-of-the-art insulation and double-glazed windows and putting in new heating and cooking systems that don't burn fossil fuels.

Few countries have begun to tackle this challenge consequentially. According to the IPCC report, 5 per cent of buildings in rich-world OECD countries alone will need to be "energy refurbished" every year from now on. New buildings will have to be constructed without emitting any $CO_2$ at all, preferably starting now. That means shifting away from carbon-intensive concrete and steel towards carbon-neutral materials, for example based on wood – or fundamentally recasting the way we make those materials.

### CHALLENGE 4: INDUSTRY

Industry is staggeringly hungry for fossil fuels – more so than buildings or transport – and its emissions are growing. Producing metals, pulp and paper, chemicals, concrete and minerals uses copious amounts of coal and other fossil fuels for heat and steam. To meet net-zero emissions, these and other industrial emissions will have to be slashed, by around 80 per cent. Coal must be phased out, energy efficiency vastly increased, and processes electrified wherever possible.

The 2018 IPCC report admits that it will take massive investment in R&D to roll out new, carbon-free industrial processes for making things such as cement, iron and steel. And that is simply to hit what is called the "overshoot target", of going over 1.5°C for a few decades before clawing our way back (see graphic, below).

That doesn't doom us to failure, says climate scientist Piers Forster at the University of Leeds, UK. "We do have the technologies, but we have to make them cheaper, more affordable, and make them work at a much bigger scale." That means not just CCS, but greener processes for making aluminium, steel, cement and the rest, for example using hydrogen rather than coking coal to make steel from iron. Perhaps the most promising solutions are the simplest: to use less of the most energy-intensive materials, and where we do, recycle more.

### CHALLENGE 5: LAND USE

The fifth challenge is in some ways the trickiest of all. At present, land use accounts for about a quarter of carbon emissions. Getting that to net zero is a game of complex trade-offs. Land can be used as a carbon sink, but we also need it to grow food, which inevitably emits $CO_2$.

That does at least give us multiple buttons to press. "There's a whole portfolio of actions, and if you push hard on one you can push less hard on the others," says Drew Shindell at Duke University in North Carolina.

To cut a very long story short, the best way forward is to intensify agriculture while reducing our consumption of foods whose production results in lots of greenhouse gas emissions, predominantly those that come from cattle. Reducing our use of ruminant animals allows us to swap pasture for forest, while finding room to grow biofuels for aviation and other forms of transport. Pasture, especially with cows on it, is a gigantic source of both $CO_2$ and methane. Forests, on the other hand, pull $CO_2$ out of the air, so reducing deforestation is also a must.

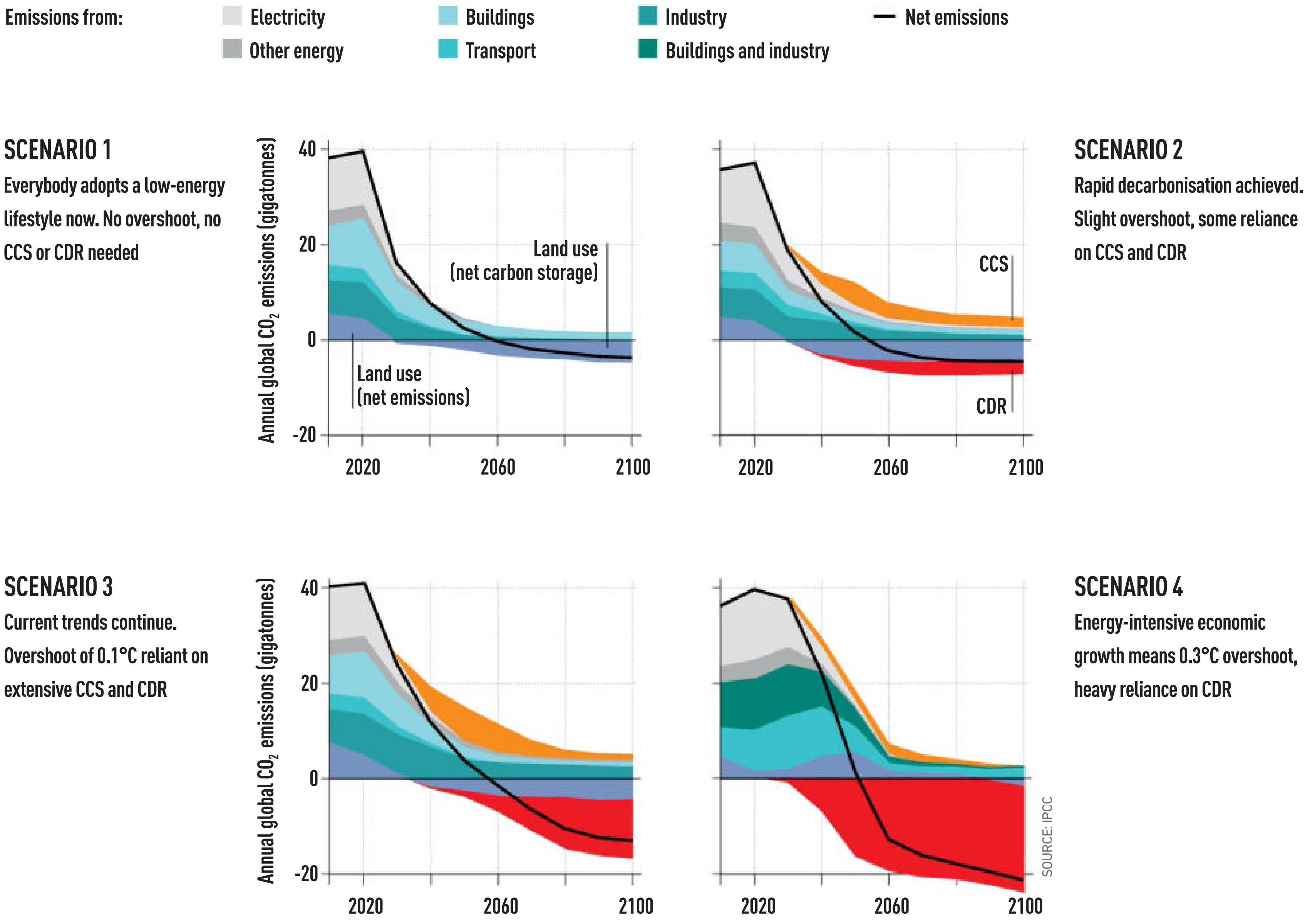
Unfortunately, current climate policies often show anything but joined-up thinking in this regard. Take biofuels. Growing use of biodiesel, a supposedly greener alternative to oil-based fuels for transport, is responsible for 90 per cent of the increased demand for vegetable oil since 2015, says Tim Searchinger at Princeton University. In Europe, more than half of imported palm oil ends up powering cars, driving the destruction of wildlife and carbon-rich forests in South-East Asia for palm oil plantations. Europe is also fuelling deforestation elsewhere by importing wood to burn for energy, while still counting this as reducing carbon emissions.

The calculations are complex: a few biofuels, mainly those made from genuine waste, can be beneficial overall. But many policies wrongly treat any biofuel as green. With the aviation industry now eyeing biofuels to reduce their dependence on oil, matters could get even worse. Work through this challenge sensibly by mid-century, however, and we're close to the ultimate goal. Close – but no banana.

### CHALLENGE 6: NEGATIVE EMISSIONS

The goal of net-zero emissions doesn't mean emitting nothing at all. Some emissions are from sources that we don't know how to eliminate, such as nitrous oxide from agricultural fertilisers, and others are too hard ›

Scenarios to meet net-zero emissions targets rely to differing degrees on "negative" emissions through industrial carbon capture and storage (CCS) and unproven carbon dioxide removal (CDR) technology



SOURCE: IPCC

to get rid of entirely. To limit global warming to 1.5°C, these remaining emissions must be balanced out by using carbon dioxide removal (CDR) technologies to remove $CO_2$ already in the atmosphere. As the IPCC says: "All analysed 1.5°C-consistent pathways use CDR to some extent."

If machines that sucks $CO_2$ out of the air sound like science fiction, natural machines for doing that exist in abundance: trees. One estimate is that forests would naturally grow on an additional 900 million hectares around the world, which is probably room for 1.2 trillion trees that could store 100 to 200 billion extra tonnes of carbon. Whether that's feasible depends on how we progress with challenge 5, but it does suggest tree-planting could be one of the most effective measures available to us to mitigate climate change.

But even a trillion trees won't be enough. Other approaches include BECCS, or bioenergy with carbon capture and storage: you grow biofuels, burn them and then sequester the $CO_2$ using the CCS technologies being simultaneously developed in level 4. There's currently only one BECCS facility operational with $CO_2$ storage, in Illinois in the US, but this decade it could be joined by plants in the UK, Norway and Japan. Meanwhile the science-fiction solution, known as direct-air capture, is moving closer to science reality. Typically, the idea to use fans to draw air into a machine where chemical sorbents capture the air's relatively dilute amounts of $CO_2$.

But no CDR technology is yet a shoo-in, said the IPCC in 2018: "CDR deployed at scale is unproven and reliance on such technology is a major risk in the race to limit warming to 1.5°C". It's not the biggest challenge, either.

### CHALLENGE 7: OURSELVES

This last challenge is the most difficult because it requires us to confront our own weaknesses. "We have to address demand," says Forster.

This could be the real sticking point. When we talk about power generation, transport, industry, buildings and agriculture, we are talking about our own actions. If on any given day you use an electrical appliance, spend time inside a building, use hot water, travel anywhere in a vehicle or buy or eat anything, you are contributing to the problem. Changing that means making sacrifices, starting today: driving less, flying less, consuming less meat, having fewer children.

→
See chapter 6 for more on climate change and you

Things are starting to change, says Forster, although not fast enough. Sales of electric cars are increasing – but so are those of gas-guzzling SUVs. More people are cutting down on meat – but more people are also eating meat, too.

What is still lacking is political will. "We're talking about the biggest transformation ever, and we're expecting policy-makers to drive it," says Michael Grubb at the Institute of Sustainable Resources at University College London. "Is that conceivable in a democracy?"

Caroline Lucas, the UK's only Green Party MP, thinks it is – but only through people power demanding the sort of changes that will see us through challenges 1 to 6. "It's clear we're going to need a mass movement," she says. "As people come to see that green alternatives improve our quality of life, as well as the state of our environment, I believe we can persuade politicians to take action."

One way or another, big change is coming. It is up to us to decide in what direction. Even if we fail and go over 1.5°C, every bit of extra warming we shave off makes the world more liveable. And if we overshoot a little, we may be able to claw our way back. "We have an opportunity," says Forster. "Not only to solve climate change, but also to really make the world far better." ∎

## THE COST OF CARBON

A central plank of plans to combat climate change is the principle that greenhouse gas emissions should be paid for. Governments can implement this in several different ways, from direct carbon taxes – in which governments put an explicit price on the right to emit greenhouse gases – to "shadow pricing" in the form of regulations that discourage carbon-intensive industry.

Most countries already have a piecemeal carbon tax, in the form of special levies on petrol, for example. The main aim here is generally to raise revenue. In contrast, some schemes afoot now, for example in the European Union and Canada, plan to impose a flat tax per tonne of carbon dioxide or equivalent, with the aim of nudging entire economies away from polluting activities. As economies adjust, the carbon price is gradually raised, with the aim of promoting a virtuous circle of lower-carbon living.

That has the potential to be very unpopular. For that reason, economists suggest the best move is to rebate the money raised to individual consumers, particularly the less well-off. It might seem pointless taking money and giving it back. But it means that products like food or fuel that are more carbon-intensive are also more expensive. This could help change consumer behaviour while not putting anyone at any overall economic disadvantage.

Canada's federal carbon tax plan has all these features. Its carbon price, currently $30 a tonne, is planned to rise to $170 a tonne by 2030. The system is designed so that people in the bottom two-thirds of the income bracket get a rebate that pays them more than they put in, in the form of a quarterly "carbon dividend" to their bank account.

# 100 PER CENT RENEWABLES

**Hitting climate targets means weaning electricity generation fully off fossil fuels, and extending electrification in transport and industrial processes, too. Thanks to new tech that keep things humming even when wind and sun aren't there, that goal seems increasingly reachable.**

UNTIL recently, our quest for clean energy was mired in imponderables. Nuclear fission power is expensive and mired in controversy. Nuclear fusion, directly harnessing the kind of reactions that power the sun, remains a distant dream. Meanwhile, renewable energy is too unreliable to meet all our power demands.

That last statement is where the running has changed. Clean energy from wind and solar has come on in such leaps and bounds in the past decade or so that an impassioned debate has broken out among energy experts as to whether "100 per cent renewables" is now within our grasp – and, if so, how we get there. "We can really mess this up," says Dan Kammen at the University of California, Berkeley. "Just because we can make the shift doesn't mean we will."

As the price of renewable energy has fallen on the back of better wind turbines and more efficient solar panels, installed capacity has been surging. In 2017, the world added 98 gigawatts (GW) of solar energy – more than any other energy source. Over half of that, 53 GW, was in China, which has long been the world's biggest consumer of dirty coal. Numbers have increased still further since.

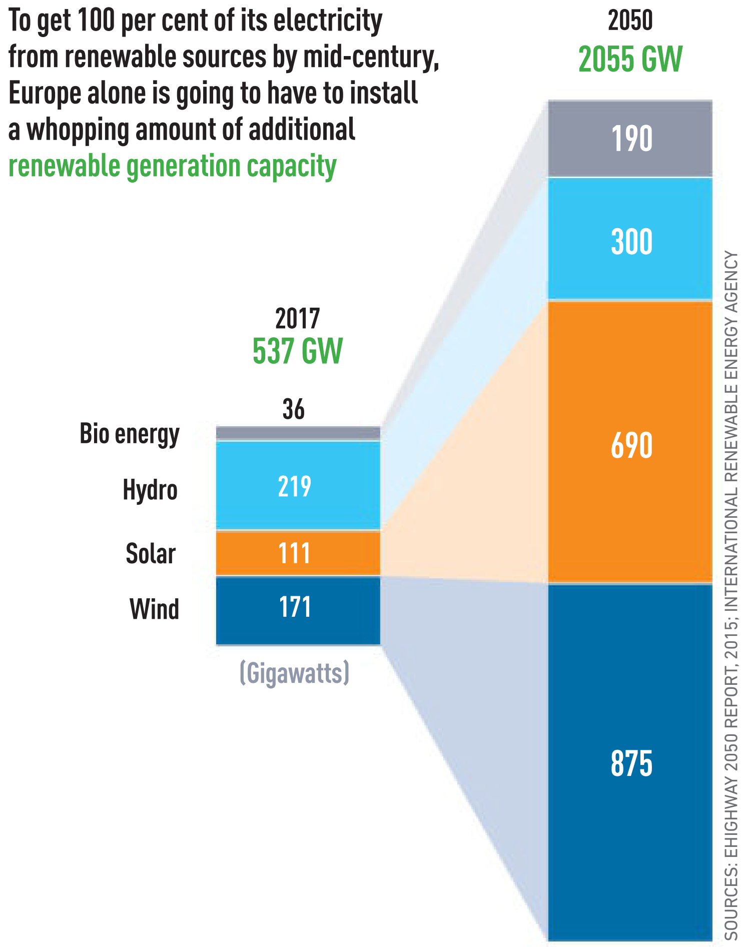
In California, the world's fifth-largest economy, renewables already provide over a third of electricity and will surpass 50 per cent well before 2030. Germany is aiming to get at least 80 per cent of its power renewably by 2050. Even oil and gas nations are setting ambitious renewables goals – the United Arab Emirates, for instance, plans to shift 44 per cent of its power to renewables by 2050.

Meeting a 1.5°C target requires more than just revamping the power grid, however. Energy efficiency must increase across the board, and converting services that currently run on fossil fuels, from transportation and heating to heavy industry, is crucial: the stuff we plug in today accounts for a measly one-fifth of global carbon emissions from energy.

That is a huge undertaking. Right now, the world gets just a quarter of its electricity from renewables. In Europe, grid experts estimate that renewable generation must quadruple by 2050 (see diagram, opposite). China, the world's biggest carbon polluter, has been leading the way. Between 2000 and 2016, electricity's share of total energy there doubled from 11 to 22 per cent, and it will exceed 50 per cent by 2050, according to Shu Yinbiao, chairman of the State Grid Corporation of China.

Arguments around whether electricity can be sourced 100 per cent renewably revolve around one inescapable fact: both the wind and the sun are capricious. The sun goes down, the wind drops, and seasons vary every year. The supply of renewable energy can plummet inconveniently just when local demand is peaking (see diagram). Currently carbon-belching natural gas turbines that ramp up and down at will are used to fill in the gaps. To guarantee "baseline" power in a zero-carbon world would require either nuclear reactors or coal or gas generators that capture the carbon dioxide they produce. But they are all punishingly expensive to build and operate, and nuclear in particular enjoys precious little public support.

The variability challenge really starts to bite when renewables make up about 70 to 80 per cent of all



To get 100 per cent of its electricity from renewable sources by mid-century, Europe alone is going to have to install a whopping amount of additional renewable generation capacity

SOURCES: EHIGHWAY 2050 REPORT, 2015; INTERNATIONAL RENEWABLE ENERGY AGENCY

generating capacity, according to modelling by the Hawaiian Electric Company. Hawaii is the only US state that's already mandated to get to 100 per cent renewable power by mid-century – an ambition the company's vice president Colton Ching calls "big, hairy and audacious". But there are cunning ways to get round it.

The cheapest bet is a strategy known as demand management – manipulating energy demand at certain times to keep the grid in balance. Operators such as National Grid in the UK already give businesses incentives to trim their usage at times of peak demand or ramp it up when supply is surging. But the process is growing increasingly sophisticated. Smart meters and machine learning techniques enable grid operators to deftly tweak the growing number of residential devices linked to the web. In future, myriad appliances will be automatically activated when renewables are running hot and dialled-down when they are not.

The trick is to make demand management work for consumers, says Lindsay Anderson at Cornell University in Ithaca, New York. That means not only tweaking loads intelligently to avoid inconvenience, but also crafting rates that reward the use of renewable energy. "A lot of it can actually be invisible to the consumer while being a huge benefit to the grid," she says. "We have the technologies that we need. We just have to use them in creative ways."

But 100 per cent renewables grid will also need capacity to store electricity for when it's needed. Supercharged batteries such as the sprawling lithium-ion facility Tesla has installed in Jamestown, Australia, are an obvious option. Boasting a capacity of 100-megawatts, this is the world's most powerful battery, for now at least. It can power up to 30,000 homes – albeit just for an hour.

In fairness, the Tesla battery was built as backup for South Australia, which has suffered a series of recent blackouts. Even so, its limitations go to show that although batteries could plausibly hold enough juice to cope with day-to-day peaks in demand, at present their cost makes them a prohibitively expensive answer to monthly and seasonal fluctuations, which are by far the biggest block in the road to 100 per cent renewables.

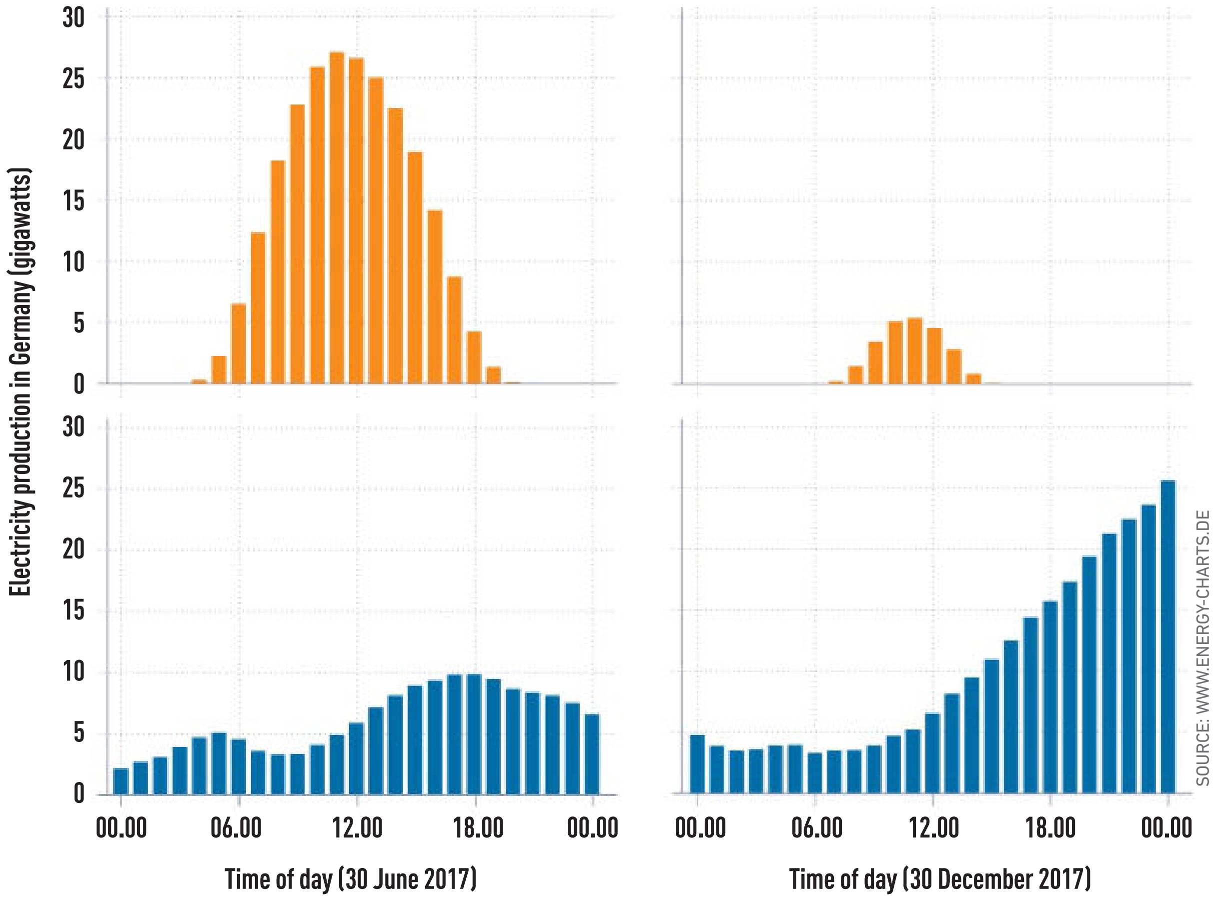
One trusty storage technology capable of doing a lot more is hydropower. Hydro reservoirs are giant reserves that store rain and meltwater, ready to be released through energy-generating turbines when demand peaks. Some hydropower plants can also use excess off-peak energy to pump water back uphill, where it recharges the reservoir, ready for another run through the power turbines. This pumped hydro technology accounts for most global electricity storage today, and there is plenty of room to grow.

China more than doubled its pumped hydro capacity over the last decade and is in the process of more than doubling this again. Technology upgrades, meanwhile, are letting places that lack hilly geography or plentiful fresh water get in on the act. Australia, for instance, is evaluating a massive coastal plant to store power by raising seawater from Spencer Gulf to a reservoir 260-metres above sea level on the adjacent plateau.

But tapping hydropower for storage is complicated by other environmental concerns. Most of the water that drives the power-generating turbines must also sustain river ecosystems, irrigate crops and slake the thirst of cities. Then there's the need to flood tracts of land for reservoirs, often displacing settled communities.

Perhaps the most promising alternatives are rapidly improving techniques that convert surplus electricity into combustible hydrogen, methane or even synthetic diesel – fuels that, unlike electricity, lend themselves to bulk storage. Power to Gas (PtG), as it is known, begins by using electricity to split water into hydrogen and oxygen. The energetic hydrogen gas can then cleanly fuel cars and trucks or fire-up industrial boilers – although questions have been raised as to ›

Solar and wind are the most abundant sources of renewable electricity, but they are also the most variable, as 2017 data from Germany shows



SOURCE: WWW.ENERGY-CHARTS.DE

hydrogen's true green credentials (see "The hydrogen economy", opposite).

These sorts of solutions could overcome short-term variations in renewables' generating capacity over hours or days, and even take some of the strain from inter-seasonal variability. The rest will require a different approach: rather than hoarding electricity locally, share it widely. After all, the wind is always blowing somewhere, and where it's not there may be sunshine. If you can zap enough wind and solar power from one place to another, you need less in reserve. That will require continental supergrids that move power more efficiently than we do today.

The technology exists: unlike conventional AC power lines, where electricity flows near the surface of a power line, high-voltage direct current (HVDC) transmission uses its full cross-section and thus encounters less resistance along the way. It can transmit big power without big losses over thousands of kilometres. Continental supergrids can be built as soon as the power companies give the green light, says Rajendra Iyer, at General Electric's HVDC business unit. "The DC grid solutions are there. They can be deployed any time."

They already are in China, which has built a series of massive lines to supply its coastal megacities. In 2019, the State Grid Corporation of China deployed its first 1,100,000-volt DC technology: a 3324-kilometre line capable of carrying 12 GW, roughly half of Spain's average consumption, that will put idled wind and solar farms in China's north-west back in operation. Imagine solar power from the Sahara available across Asia and Europe and you get an idea of China's ambition.

For inter-continental supergrids, the biggest challenges are geopolitical and cultural. Nations must be willing to place their trust in imported energy – not so different from today's dependence on oil and gas produced in only a few parts of the world, but also not a minor complication at a time of increasing international tension. Opposition from communities that new DC power lines would traverse is another reason why Europe's transmission operators have, to date, stopped short of planning a continental supergrid.

Europe can probably get by without one. A technical study called the eHighways 2050 project, completed in 2015, suggests that Europe could shift to 100 per cent renewable power by expanding links between neighbouring countries rather than sending long lines across them. But forgoing a supergrid may raise energy costs, and even the smaller links Europe is planning face concerted local opposition.

That sort of conflict, together with the technical and economic challenges for both super-charged storage and supergrids, makes the shift to 100 per cent renewable power seem daunting in the extreme. Yet many scientists are more optimistic than ever. The real question, they say, is not whether we can get to 100 per cent renewable energy, but whether we will do it in time. ▮

# THE HYDROGEN ECONOMY

Hydrogen is the lightest element in the universe and the most abundant. Although it rarely exists on its own on Earth, it can be produced using clean electricity to split essentially inexhaustible water, producing only oxygen as a by-product.

Once made, hydrogen acts as a chemical energy carrier, rather like oil or gas, that can be piped or transported to where it is needed. It stores three times as much energy per unit of mass as conventional petrol. When it "burns" in air – releasing that stored energy – it simply combines with oxygen to produce water again. In that sense, it is the ultimate green fuel.

Small wonder that across the world, there's renewed interest in the " hydrogen economy", wth hydrogen used as a fuel  to decarbonise "hard-to-abate" sectors difficult to power directly with clean electricity. Besides being used as a carrier to store energy from the electrical grid when supply from renewables is high and demand is low, these range from long-distance road haulage, aviation and shipping to naturally carbon-intensive industrial processes such as steel and petrochemical production. Hydrogen might also replace natural gas, or methane, for home heating. The European Commission's Joint Research Centre says that between 10 and 23 per cent of the EU's final energy consumption could be covered by hydrogen in 2050; the energy company Shell puts the figure at 10 per cent globally by 2100.

But hydrogen might not be all it's cracked up to be. Humanity already produces around 70 million tonnes of hydrogen each year, mainly for use in making ammonia fertiliser and chemicals such as methanol, and to remove impurities during oil refining. Some 96 per cent of this hydrogen is itself made directly from fossil fuels – mostly natural gas, followed by coal and then oil. This overwhelmingly uses a process known as steam reformation that releases carbon dioxide.

Only 4 per cent of hydrogen is made the clean way, using electrolysis to split it out of water. Much of the electricity to supply even that measly share of the hydrogen market comes not from green sources, but from fossil fuel power plants. Far from being green, the hydrogen produced globally today has a carbon footprint on a par with the UK and Indonesia combined – about 830 million tonnes of $CO_2$ annually. What's more, truly green hydrogen is a lot more expensive to make – about four times so than conventional "grey" hydrogen.

A middle way is "blue" hydrogen made the conventional way, but "burying" the emissions associated with producing it using carbon capture and storage (CCS) technology, which exists only on a pilot scale so far. Jan Rosenow at the Regulatory Assistance Project, a non-profit organisation that works to expedite a clean-energy transition, disagrees. He likens blue hydrogen to the coal industry's attempts 15 years ago to promote "clean coal" plants fitted with CCS. That never happened, because the rapidly falling cost of alternatives including renewables rendered it uneconomical.

For many hard-to-abate sectors, however, we have few alternatives on the table. "If we don't have [clean] hydrogen available by 2030 or 2040, we think we're going to be in a sticky place for some of these sectors," says Simon Bennett at the International Energy Agency. "There are certainly risks on being overly bullish on the future hydrogen economy," he says. "But I think it's a bad time to be an out-and-out sceptic because there's clearly momentum and funding going into projects in the short term regardless." The question today no longer seems to be if hydrogen will help us fight climate change, but a matter of whether it ends up as the star turn or just a bit player.

# 18 SOLUTIONS TO SAVE THE CLIMATE

**Nobody said it would be easy – but maybe it isn't as hard as we think. All around the planet, countries are deploying technologies that reduce carbon emissions in the big areas where radical change is needed: energy generation, transport, industry, buildings and land use.**

IN 2015, 12 leading environmental institutions from around the world, led by Finland's national innovation fund, SITRA, set out to assess the potential of emissions-reducing innovations. "At the start of the project, we had a very simple question in mind," says SITRA's Outi Haanperä. "How far could we go just using and scaling up existing technologies?"

Quite a way. The assessment identified 18 solutions that, rolled out as widely as possible, would cut global emissions by about 12 gigatonnes of carbon dioxide annually by 2030, or 25 per cent of projected emissions if countries stick to their commitments under the 2015 Paris climate change deal. Implementing them would cost $94 billion a year, less than a fifth of what governments currently shell out in direct fossil-fuel subsidies. Add in the benefits to economic growth, sustainable development and poverty reduction, and many are an economic win, even before you consider the costs to health, wealth and the environment of doing nothing. We approach them in reverse order.

### 18. ENERGY GENERATION: OFF-GRID SOLAR, BANGLADESH

In Bangladesh, 50 million of the country's population of 165 million still have no access to grid electricity. Dirty, inefficient kerosene lamps are the main source of lighting. Since 2002, however, the country's Solar Home Systems programme has brought off-grid electricity to some 20 million people in 4.5 million households, saving about 580,000 tonnes of $CO_2$ emissions. Other countries with significant off-grid populations in Africa, the Caribbean, Central America and the Asia-Pacific region could similarly benefit.

**Potential annual global $CO_2$ saving by 2030: 3 million tonnes (Mt)**

### 17. TRANSPORT: BETTER BUSES, COLOMBIA

Extensive, organised public transport systems are a given in much of the rich world, but less so in many rapidly developing cities. Yet commuters in Bogotá, Colombia, have one of the most efficient, climate-friendly bus systems in the world. The buses of the TransMilenio Bus Rapid Transit system, inaugurated in 2000, run on diesel, but the system saves 6000 tonnes of carbon emissions a year by displacing journeys on other, less efficient vehicles for a cost a fraction of a tram or subway system. Many other cities in middle-income countries, notably China and India, might follow Bogotá's lead.

**Potential annual global saving: 24Mt**

### 16. BUILDINGS: HOME INSULATION, GERMANY

The Kreditanstalt für Wiederaufbau, or Reconstruction Credit Institute, was established as part of the US-funded Marshall Plan to help rebuild Germany following the second world war. Its priorities are now somewhat different. Between 2006 and 2014, it funded energy efficiency retrofits or the construction of nearly 4 million German homes, cutting emissions by an estimated 700,000 tonnes. Other high-income nations with chilly winters, among them the US, Canada and Japan, could follow suit.

**Potential annual global saving: 77Mt**

### 15. INDUSTRY: PIMPED-UP ELECTRIC MOTORS, UNITED STATES

For all its reputation as a climate laggard, the US has strict government-imposed energy efficiency rules. One of the most successful is for industrial electric motors used to power fans, pumps, conveyors and compressors. Rigorous standards for all motors up to 500 horsepower (373 kilowatts) have saved at least 28 million tonnes of $CO_2$. Rolled out worldwide, this measure could more than pay its way through electricity cost savings.

**Potential annual global saving: 112Mt**

### 14. BUILDINGS: GREEN MORTGAGES, MEXICO

In 2010, Infonavit, the largest mortgage lender in Mexico, launched a government-subsidised "green mortgage" scheme to encourage buyers into houses fitted with technologies such as solar water heaters, low-energy lighting, water-saving taps and thermal insulation. The scheme has saved only a modest 300,000 tonnes of carbon, but, according to the SITRA analysis, has enormous potential in other countries with similar climates, including Australia, China, New Zealand, South Africa and Spain.

**Potential annual global saving: 125Mt**

### 13. ENERGY GENERATION: ROOFTOP WATER HEATERS, CHINA

Roofs festooned with racks of shiny black pipes are a feature of many Chinese towns and cities. Since 2014, they have been compulsory in all areas with more than 2200 hours of sunshine a year. In 2013, the heaters were estimated to be saving China 76 million tonnes of carbon emissions annually. If adopted in other countries with suitable amounts of sunlight, particularly in Asia and Africa, that amount could almost double.

**Potential annual global saving: 136Mt**

### 12. LAND USE: RESPONSIBLE FARMING, BRAZIL

Land use, such as farming and forestry, currently accounts for about a quarter of all carbon emissions. To meet the 1.5°C target, it needs to become a net carbon absorber by 2030. Until the election of populist president Jair Bolsonaro, Brazil had the world's most ambitious programme to reduce agricultural carbon emissions. Giving farmers incentives to restore degraded pasture, plant trees and reduce fertiliser use are low-cost solutions that are appropriate for large swathes of the developing world.

**Potential annual global saving: 165Mt**

### 11. ENERGY GENERATION: WASTE WOOD BURNING, FINLAND

Finland generates about a fifth of its energy from waste wood – from construction and the pulp and paper industries – and other biomass, saving around 6.8 million tonnes of $CO_2$ a year. Biomass energy is subsidised and wood pellets are increasingly used to directly heat buildings and district heating networks. With appropriate air-quality controls in place, that could be scaled up to other cold countries with lots of waste wood, such as Canada, Mongolia and Russia.

**Potential annual global saving: 193Mt**

### 10. LAND USE: REDUCE FOOD WASTE, DENMARK

In 2010, the Danish government assessed how much food was wasted between production and consumption. The result: 586,000 tonnes, creating unnecessary carbon emissions from land use, transport, storage, packaging and composting. Since then, various initiatives, including better packaging and a restaurant doggy-bag scheme, have cut that number by 25 per cent. If replicated across high and middle-income countries, that cooks up a delicious win.

**Potential annual global saving: 238Mt**

### 9. INDUSTRY: STOP METHANE LEAKS, UNITED STATES

A voluntary scheme that began in the US in the 1990s cut leaks of the greenhouse gas methane from oil and gas production. The saving is equivalent to 38 million tonnes of $CO_2$ every year – a huge win even on modest assumptions as to the extent it could be rolled out worldwide.

**Potential annual global saving: 388Mt**

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### 8. INDUSTRY: MORE EFFICIENT GADGETS, JAPAN

With limited fossil fuels of its own, Japan relies almost completely on imports. In 1998, it launched a programme called Top Runner to improve the energy efficiency of machinery and appliances from air conditioners to electric toilet seats. Manufacturers of cars, household white goods, electronics and vending machines had to make improvements, or face being named and shamed. Japan's emissions are estimated to have fallen by around 50 million tonnes a year as a result, with big savings possible in other big industrial economies.

**Potential annual global saving: 400Mt**

### 7. TRANSPORT: CLEAN UP CARS, EUROPEAN UNION

Since 2009, new cars sold in the European Union have had to meet tough environmental standards, in effect producing no more than 130 grams of $CO_2$ per kilometre on average. By 2012, the average $CO_2$ emissions of new cars had fallen to close to 132 grams per kilometre. Car-makers were later found to be fiddling the testing system, but similarly enhanced, properly policed standards across the globe could make a huge difference.

**Potential annual global saving: 525Mt**

### 6. INDUSTRY: INDUSTRIAL EFFICIENCY, CHINA

A bit of command and control goes a long way in increasing energy efficiency. China's 12th five-year plan (2011-2015) ordered the country's 10,000 biggest energy guzzlers to become more efficient. The energy efficiency of Chinese industry improved by between 3 and 4 per cent annually in that period, and continues to increase. If applied to other economies with low industrial energy efficiency, notably India, South Africa and the former Soviet republics, it is a heavy-duty win.

**Potential annual global saving: 879Mt**

### 5. LAND USE: REFORESTATION, COSTA RICA

This Central American nation is a renowned green pioneer. In 1980, forest covered just 20 per cent of the country. It now carpets more than half, thanks largely to payments for reforestation and ecosystem preservation. Costa Rica's land-use sector has moved from being a net emitter of $CO_2$ to a net absorber, to the tune of 3.5 million tonnes a year. Many countries across the world have a similar potential for reforestation.

**Potential annual global saving: 882Mt**

### 4. BUILDINGS: NO MORE STOVES, CHINA

China's snappily titled National Improved Stove Program was launched in the early 1980s to encourage people to improve air quality by getting rid of old coal or wood-burning stoves and installing efficient gas-fired ones instead. Around 200 million households upgraded, and 90 per cent of people now have access to clean-burning stoves. The programme also cut greenhouse gases by between 1 and 3 tonnes per stove per year. An International Improved Stove Program could take in many low-income countries that still rely on traditional cooking stoves.

**Potential annual global saving: 985Mt**

### 3. ENERGY GENERATION: MORE WIND TURBINES, DENMARK, BRAZIL

Denmark produces about half its electricity from wind. In Brazil, turbines in the windy north-east already generate about 8 per cent of the country's electricity. The current savings are 8.6 million tonnes of carbon emissions a year in Denmark and 1.1 million tonnes in Brazil. If high and middle-income countries exploited their wind resources to the same extent as Denmark, and low-income countries to the same extent as Brazil, the total win is over 1 gigatonne.

**Potential annual global saving: 1018Mt**

### 2. LAND USE: REDUCE DEFORESTATION, BRAZIL

Between 2004 and 2012, Brazil reduced annual deforestation by 84 per cent through a mixture of bolstered law enforcement, expanded protections and economic incentives, saving over 400 million tonnes of $CO_2$ a year. Deforestation rates have since rebounded since Bolsonaro's election, but Brazil's success in this golden period shows what other countries with extensive rainforest cover could do.

**Potential annual global saving: 2800Mt**

### 1. ENERGY GENERATION: ON-GRID SOLAR, GERMANY

Nearly 20 years ago, Germany passed a law to promote electricity generated from the sun and wind. Green electricity producers got a guaranteed price and first dibs on feeding electricity into the grid. Today, 25 per cent of Germany's electricity comes from renewable sources, and a quarter of that is solar. If all countries with sufficient sun were to exploit grid solar energy to the same degree, there would be an immediately brighter future for the fight against climate change.

**Potential annual global saving: 3200Mt** ■

# "BUSINESSES NEED A CREDIBLE CLIMATE TRACK RECORD"

Getting investors on side will be key to progress towards net zero, says ex-governor of the Bank of England Mark Carney.

**In your book, you say that new "technologies" are needed in the spheres of engineering, politics and finance to tackle climate change. How are we doing with those?**

I think we are getting there. We've left it very late. But we now have engineering solutions that brilliant minds have developed and that companies have made much more economic. About two-thirds of emissions can be economically reduced today. There are pathways for the other third, but there need to be some breakthroughs; that is still in the realm of venture capital. But people recognise that if they can crack, say, green hydrogen as a fuel for trucks or direct air capture of carbon, there will be an enormous use for those and they or their company will make a lot of money. So we're finally seeing effort, capital and focus flowing into those.

On the political side, we have moved on from a world where the scale of the effort required to deal with climate change wasn't appreciated and where the effort was slow and fragmented. There is increasingly a recognition that we need to get to net-zero greenhouse gas emissions and keep net warming below 2°C, and ideally below 1.5°C. This is to the credit of those who've helped spur the change through social movements, many of them led by young people.

**What financial technologies are needed to turn things around?**

You need information, financial tools and some pricing mechanisms. With those in place, the financial market will pull forward the adjustments that are needed, recognising that net zero is a core political goal, that

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## PROFILE
## MARK CARNEY

Mark Carney was governor of the Bank of England from 2013 to 2020, and before that of the Bank of Canada. He is the UN special envoy for climate action and the finance adviser for the UK government's presidency of the UN's COP26 climate summit, and the author of the book *Value(s): Building a better world for all*

## CLIMATE FINANCE AND LAW

**The fight against climate change has traditionally been the preserve of scientists and activists such as Extinction Rebellion and Greta Thunberg's Fridays for Future school strikes movement. But the financial and legal systems are increasingly lending their support too.**

Writing net-zero targets into law, as countries such as the UK and Sweden have done, has a significant, if obvious, consequence: governments can be challenged in court if they enact policies that might fall foul of them. Since enacting its net zero commitment in 2019, the UK government has been the subject of litigation about airport expansion and road building policies.

Even without such legally binding targets, climate change is increasingly ending up in the courts based on more general legal principles. In a high profile case in the US, in 2015 a group of "climate kids" sued the US government over its climate change policies, on the basis they violated their constitutional rights to life, liberty and property by not halting global warming. The case was finally dismissed by a federal appeals court in 2020. The presiding judge agreed with many of the kids' assertions, writing in a 32-page opinion that "the federal government has long promoted fossil fuel use despite knowing that it can cause catastrophic climate change", but arguing it was not within the courts' right to compel the US government to phase out fossil-fuel use.

In the first positive decision of its kind, however, the Netherland's Supreme Court in 2019 upheld a ruling by a lower court forcing the government to meet emission reduction targets. In April 2021, the Germany's supreme constitutional court struck down elements of the German government's Climate Action Law, which aimed for a 55 per cent emissions reduction by 2030 and net zero by 2050, upholding a claim by young activists that the protracted timescale compromised their fundamental rights have their life and health protected.

Climate polluters are also feeling the heat. In May 2021, a Dutch court ruled that the oil company Shell must align itself with the Paris Agreement on climate change and cut its carbon emissions, including from the products it sells, by 45 per cent by 2030. Shell announced that it would appeal, but until that appeal is heard the ruling is legally binding on the company.

Such judgments could be significant, and not just for their legal force. The changing legal landscape is increasingly making big investors nervous about investing in climate polluters.  Over $30 trillion of money in rich-world companies is controlled by pension funds, who have a "fiduciary duty" to invest money in a way that is in their clients' best interests. Many fund managers have historically interpreted this as maximising the short-term value of the fund, regardless of the social, environmental or ethical consequences – places like fossil fuel companies.

But in 2014, the UK Law Commission decided that, although trustees' primary goal is indeed financial return, they can also take a longer view and consider non-financial factors, such as the social, environmental and ethical concerns of investors. That allows managers to avoid investments that may pay out in the short term but risk making their clients' futures more precarious, say by accelerating climate change.

Whether offloading unsustainable stocks is the right strategy is another matter. Called divestment, this tactic has been employed by large-ish, high-profile investors such as universities and religious organisations. "The aim is to do the company financial and reputational damage," says Michael Kind of UK pressure group ShareAction.

But even if a pension fund or other investor offloads shares, somebody else is buying them, which is why some favour the alternative strategy of engagement: using investments as leverage to force companies to adopt climate-friendly policies. "Shareholders have huge power to create change within companies," says Kind. And they are increasingly prepared to use it. Coincidentally on the same day as the Shell judgment, activist investors voted to make US oil firm Chevron responsible for reducing the emissions from customers burning its products, while a small hedge fund forced ExxonMobil to accept two pro-environment members on its board.

New legislation in the EU and UK will soon require greater disclosure of companies' exposure to climate change, and their contribution to it. Behind the scenes ahead of this November's crucial COP26 climate summit, there is a global push to agree similar financial reporting and transparency rules. Capitalism helped cause climate change – now it might just help fix it.

REUTERS/ALAMY STOCK PHOTO

Given the right incentives, markets can help fight climate change, says Mark Carney

the engineering technologies exist to advance it and this is where people want to invest.

This is just beginning to happen at scale. Through COP26 in November, we're looking to really accelerate this progress, to get the core of the financial system around the world – banks, pension funds, asset managers – committed to net-zero transparency, so that people can see where institutions stand. That brings these three elements – engineering, political and financial – together, and it has the potential to be exceptionally powerful. The big caveat is that we really need it to be powerful, given how late we've left it.

### Are politicians still only talking the talk on climate change?

Current policies are better than previous policies, but they are still not enough. There has been big progress in that there are much clearer signals about what isn't going to be allowed. Knowing, for example, that there will be no new internal combustion engine vehicles from 2030 in the UK and Europe sends a message to the auto industry to get on with developing electric vehicles and charging infrastructure. It tells consumers that if you buy a diesel or petrol vehicle in the latter half of this decade, you will be buying obsolescence. What's important for business is that there is a credible track record demonstrating that governments will do what it takes. In countries like the UK, that track record is now lengthening.

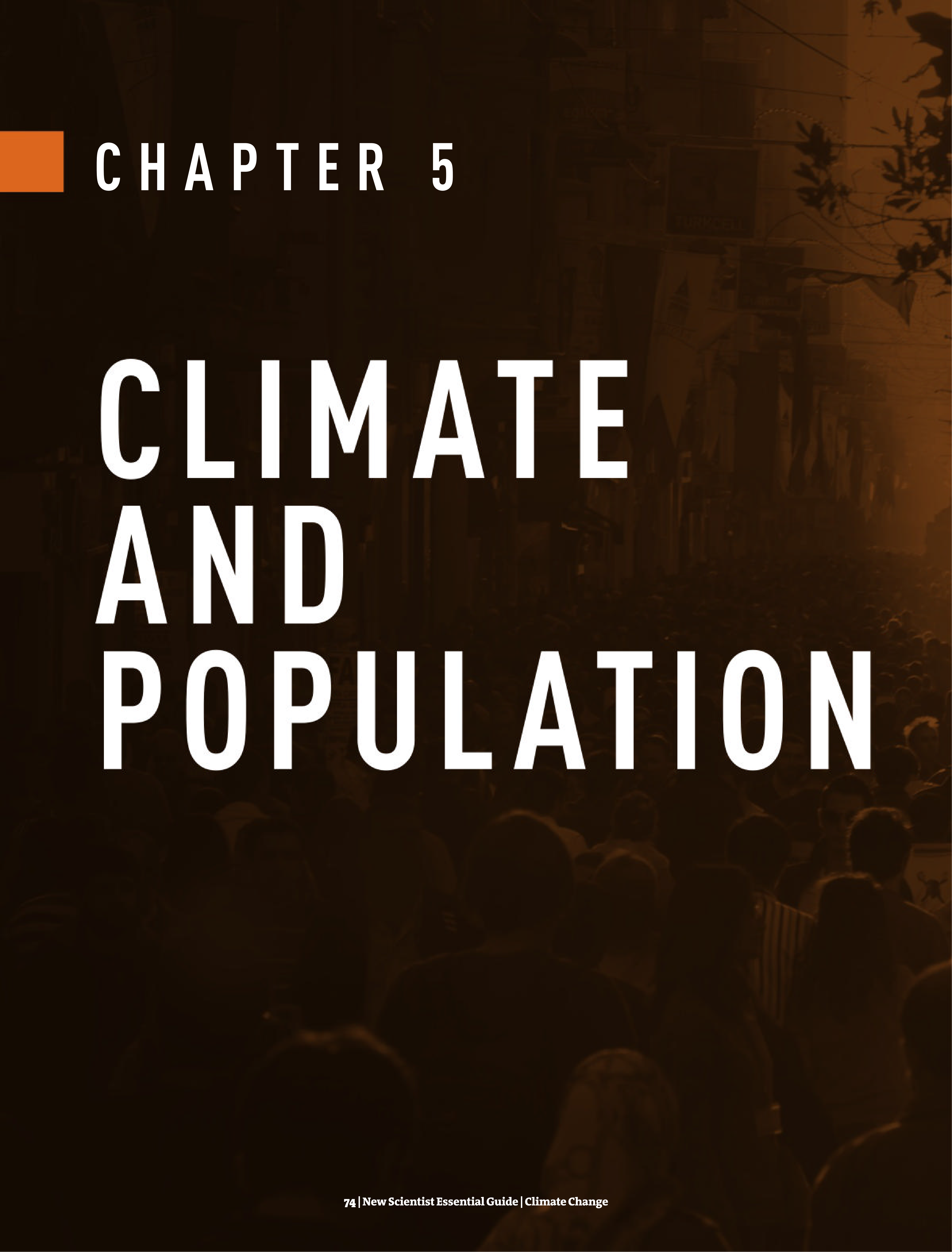
### Should we also be penalising polluting industries by divesting from them?

Certain industries do have huge emissions. The energy sector, steel and cement are examples. But I wouldn't advocate a blanket sale of shares in every company in, say, the energy sector because some are reinvesting their money in a green future. The companies that can do most to reduce emissions are actually some of the ones you want to back – you go to where the emissions are. The question to pose for any individual company is: what is it doing with its business strategy and investments to reduce its impact on the planet?

Again, with COP26, we're trying to help with this through some of the plumbing-type work for the financial sector, establishing reporting requirements so that every bank, pension fund, insurance company and investor can make those judgements about whether companies are being managed in a way consistent with getting to net zero. I hope with the meeting in Glasgow, we'll get to that point. Then, hopefully, more people will be asking those questions and moving their money to places that are consistent with their values.

### Do you think COP26 will succeed?

It has to. There is great momentum in civil society, and encouraging momentum in business and in finance responding to that. We've had encouraging steps taken by major countries like China, Japan and South Korea in recent months. There's the new orientation of the US administration. All of that is positive. It's a huge responsibility for the UK and, rightly, it is looking for a very high-ambition outcome. That's what the world needs. ▮



## CHAPTER 5

# CLIMATE AND POPULATION

In the past century or so, human population has boomed. That's one major factor behind the climate crisis, as more and more people consuming more create more emissions warming the planet.

So does that mean there are simply too many of us?

# THE GREAT POPULATION DEBATE

**With fewer of us around, there would be fewer greenhouse gas emissions, less pollution and waste, and more space for both us and the rest of the natural world to survive and thrive. That basic argument is hard to deny – but the question becomes what you propose to do.**

RIGHT: ORBON ALIJA/ISTOCK
PREVIOUS: KELVIN JAY/ISTOCK

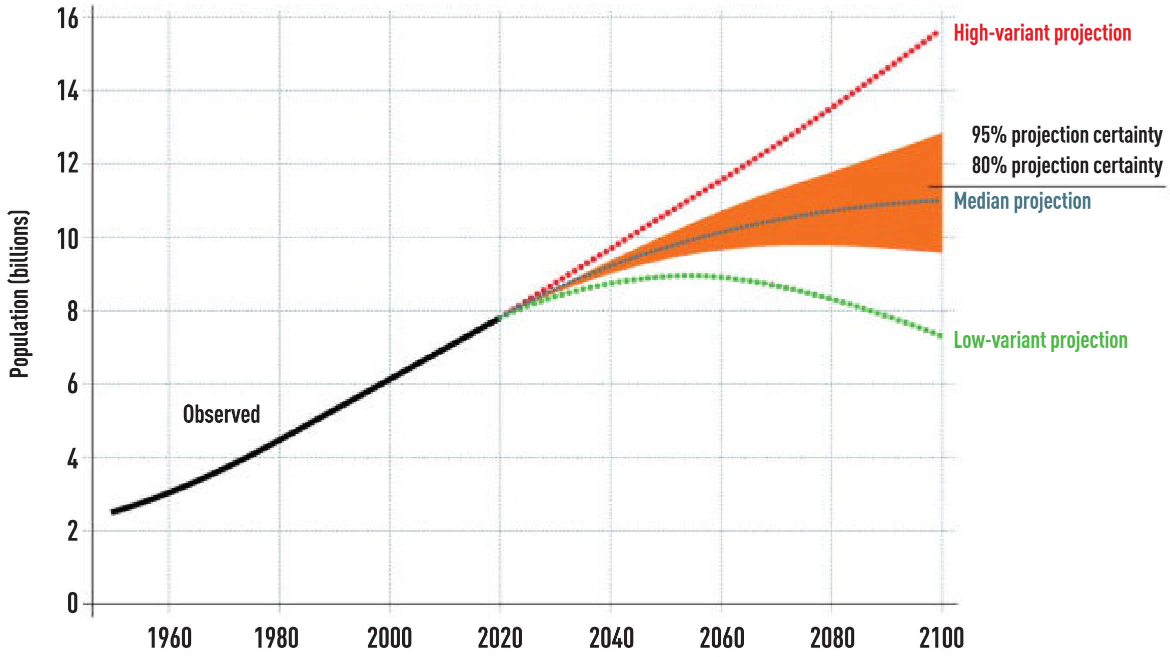
THE covid-19 pandemic has been a reminder of how little we want to return to the days when deadly infections carried away most of us. Success against infectious disease in the past century or so, alongside other improvements in health, sanitation and nutrition, have dramatically improved human survival rates. In 1860, the figure for child mortality worldwide was more than 40 per cent. Today, it is around 4 per cent, and a fraction of a per cent in high-income economies. In western Europe, life expectancy is now about 80. In sub-Saharan Africa, it is over 60, up from 44 half a century ago.

This change in death rates marks the first stage in the "demographic transition": a seismic change in which nations shift over decades from high birth and death rates to lower rates of both. Few people have a problem with its first stage. "Everybody is happy with mortality decline," says Diana Coole, a political scientist at Birkbeck, University of London.

But as more people live longer lives, populations skyrocket. The global population of around 1 billion in 1800 had doubled by the late 1920s. By the mid 1970s, it had doubled again, approaching 4 billion. Half a century later, it is about to have doubled again, standing at more than 7.7 billion.

And so it goes on. This year, more than twice as many people will be born as will die. The number of humans will swell by something like 80 million, pandemic or no pandemic. The United Nations Population Division's median projection estimates that 9.7 billion people ›

UN projections for world population diverge in the second half of the century



SOURCE: UNITED NATIONS. WORLD POPULATION PROSPECTS 2019

will be on the planet in 2050 and 10.9 billion in 2100. These figures are based on the average global fertility rate, defined as the number of births per woman. Increase that rate by half a child, and you hit a "high variant" of almost 16 billion people at the end of the century (see graph, above). "You can't read the high-population variant without thinking, 'Oh my God'," says Coole.

On the face of it, fewer people means fewer emissions and less climate impact – a better planet for all. In 2017, Kimberly Nicholas and her colleague Seth Wynes at Lund University in Sweden studied the measures people in advanced economies could take to reduce their carbon footprint. Once they accounted for the generational effect – that every child a person has is likely to have children themselves – having one fewer child was the single most effective measure an individual could take, saving 120 tonnes of carbon dioxide a year for the average US citizen. The next-biggest impact, living car-free, came in at 3 tonnes of CO$_2$ a year for the average person in the US. Trailing in behind that were avoiding flying, buying green energy and switching to a plant-based diet. "Having a child is a huge life decision personally and professionally and financially and every other way," says Nicholas. "It has a huge impact on the carbon legacy that we leave in the atmosphere."

But delve a little deeper, and things become more complex. Concerns about the ability of the planet to sustain so many of us date back at least two centuries, to the writings of the English cleric Thomas Malthus. In the 1960s, the first wave of the environmental movement brought soul-searching about global population numbers when they were barely half what they are today. In 1972, the Club of Rome, a grouping of prominent politicians, economists, scientists and diplomats, published *The Limits to Growth*, a report that used computer modelling to predict the collapse of global systems in the mid-to-late 20th century if then-current trends of population growth and resource consumption were to continue.

But from the late 1960s, the "green revolution" in agriculture began to kick in, allowing more people to be fed more securely. And the second phase of the demographic transition began in earnest, as birth rates started to fall worldwide. The drivers of this process are complex, but relate to increasing urbanisation, education and material progress. Rising levels of education lead to more people having fewer children and at a later age. Healthier, better educated women are more likely to stake their rights to opportunities beyond bearing and caring for children. Widespread availability of abortion and contraception assist those trends.

From a high point of well over 2 per cent a year in the late 1960s, the global rate of population growth has now fallen to a little over 1 per cent. Across large swathes of Europe and South America, fertility rates are at or close to the "replacement rate" of 2.1 children per woman, the level that ensures a stable population. In some parts of the world, notably Japan, South Korea, Russia and some nations in eastern and southern Europe, fertility is below this rate, and population is declining. But even in those places where it is still increasing – South Asia, Africa, the Middle East – fertility is going down.

One basic problem in talking about human population is not knowing where those trends are going next. UN projections are largely based on applying models of the second phase of the demographic transition, the fall in birth rates, in places that have already been through it to places that haven't. Some people criticise the UN's projections as too high, citing evidence that economies developing now are transitioning faster to lower birth rates than those that have already been through the demographic transition.

Not according to John Wilmoth, head of the UN Population Division. "There's really no argument for saying that change in the future will be faster than it was in the past," he says. "If anything, I think what we worry about at the UN is that the pace of change may be slower than what we're predicting."

The worsening climate crisis would certainly seem to suggest caution: rising population is still rising population. Coole is also sceptical that we are reaching the closing scenes of a grand historical narrative that ends inevitably with low mortality and fertility rates. In fact, she is worried recent trends might be about to go into reverse. Everyone is happy about mortality decline, but it is a different story with fertility decline.

There are many reasons why people and groups across the world adopt "pronatalist" positions arguing for higher fertility. One is that, while environmental considerations might suggest that lower fertility rates are good, economic considerations often suggest they aren't, at least on models of economic growth based on more people creating more demand for goods and services. Developing economies are certainly reaping the rewards of young, dynamic populations as their workforces boom – just as today's advanced economies did earlier. "If you go to India, it's incredible the change in 10 years," says Coole. "You can see why they feel this is something they want to have."

Nations further along the demographic transition, where fertility rates are bumping along at replacement level or below, are grappling with the opposite problem. With fewer people around, economic growth, stable finances and societal cohesion become harder to maintain. In states with highly developed welfare systems, this becomes a slow-burn issue of a growing "dependency ratio": a large, ageing, economically inactive population supported by tax receipts from a dwindling band of working people.

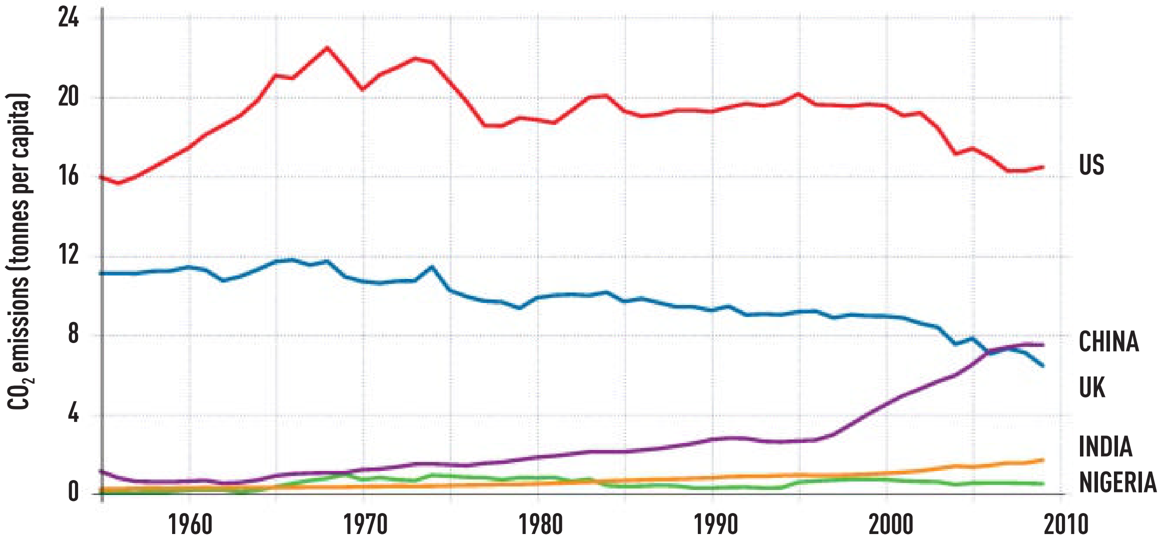
The solutions to these problems – higher taxes, less generous welfare provision, later retirement – have themselves turned into political hot potatoes in many advanced economies. One alternative – higher levels of immigration to maintain working-age populations – is even more fraught. Japan has gone down a different route: pursuing robotics as a way of replacing people not being born.

The challenges associated with ageing populations are a big factor in the success of nationalist populist movements in many parts of the world. Certainly, rhetoric advocating population growth as a matter of national destiny is on the rise in countries including Hungary, Italy, Iran and elsewhere. In countries such as Turkey and Poland, vocal pronatalist contingents are one reason why women's access to abortion is being limited. "Right across the world, we see women's rights being curtailed by people trying to increase population," says Coole. That has a certain irony about it, because a desire not to interfere with women's reproductive rights is another reason why, starting in the 1970s, talk about population control receded.

Those who suggest there might be a case for reducing population growth must certainly be prepared for a sometimes personal backlash. Nicholas stumbled onto this thorny territory with her study of the carbon effects of having one fewer child. Some, mainly male, critics, including the shock jock Rush Limbaugh, openly questioned her own reproductive choices, while some feminist critics suggested she was attempting to shift the blame for climate change from corporations and governments to women's reproductive choices.

"The decision to have a child is a deeply personal one, as it should be," says Nicholas. "Our study provided information to inform choices, but people react very strongly and emotionally if they feel their decisions are being threatened or attacked." Coole says she has had similar experiences if she seemed to imply limiting ›

The biggest factor driving global carbon emissions is per-capita consumption and this varies hugely across the world



SOURCE: WORLD BANK

reproductive freedom: "If I mentioned it, say, in the States, feminists would treat me as if I was some kind of Nazi."

That word is extreme, but it crops up a lot in discussions that touch on limiting human numbers. The genocides committed by the Nazi regime followed on from a long history of Western scientists advocating eugenics to "cleanse" populations of supposedly undesirable traits. That history dogs the conversation today. "It really caused problems among Western intellectuals," says Partha Dasgupta, an economist at the University of Cambridge, UK. "The moment you talked about population, you were talking about coercion."

No one who talks thoughtfully about population today is advocating that. In 1967, the UN recognised individuals being able to decide whether they have children, and how many, as a fundamental human right. Anti-natalism via coercion has been tried several times, with generally disastrous consequences. Sterilisation programmes across the US during the 20th century disproportionately targeted women from minority communities. China's infamous one-child policy, in place from 1979 to 2013, led to widespread selective abortion of female fetuses, as well as the enforced sterilisation of women. In some parts of India, more than 6 million men with more than two or three children were forcibly sterilised during a state of emergency from 1975 to 1977. Partially funded by aid money from the US and elsewhere, it was widely seen to have had an anti-Muslim agenda.

"Sometimes countries have reacted with such aggressive measures that they became violations of human rights," says Wilmoth. "They became convinced that it was necessary for the collective good and invading people's bedrooms and women's wombs was justified to control population growth."

That points to a problem that often crops up in debates about population: the "them" versus "us" problem. Most people, when asked to think about their own lives and those of the people around then, find themselves taking an instinctively pronatalist position. We don't like the thought that any party, state or otherwise, should be telling us how many children we should have.

Yet if we say that global birth rates are too high and need to be brought down, we are sailing dangerously close to saying something similar would be OK elsewhere. "The discussion is almost always: we want to see fewer people of the other kind, of the other race, of the other nationality," says Wolfgang Lutz, a demographer at the International Institute for Applied Systems Analysis in Austria. "You always want to see fewer of the other and more of your own."

In many developed economies, fertility rates bump along below the replacement rate, while in other parts of the globe, notably parts of central Africa, fertility rates are still running at three, four, five or more children per woman. In the UN medium-variant population scenario, half of the global population increase by 2100 comes from just nine countries, eight of them low-income economies: India, Nigeria, Pakistan, the Democratic Republic of the Congo (DRC), Ethiopia, Tanzania, Indonesia and Egypt. The US, with high levels of immigration and a relatively young population for a high-income economy, comes in at number nine.

But for Lutz, arguments based on raw numbers alone are flimsy. "People are focused way too much on world population size, which is in a way a figure that affects nobody's life, because what you experience is the population growth in your neighbourhood, or at most in your country," he says.

The justification for talking about population is concern about humanity's impact on the planet. In the case of climate change, where that is coming from is pretty clear. "If you look historically over time at what has driven the increase in carbon emissions in the atmosphere, sure, population growth has been an important factor, but a larger factor has been the change in per-capita emissions," says Wilmoth. "Depending on how you measure it, over which time period, for which population and so forth, it's something like two-thirds versus one-third: two-thirds behaviour and one-third human numbers."

That switches the spotlight away from fertility rates in "other" parts of the world back to the consumption levels of people sitting in relative prosperity in high-income economies (see diagram, left). "Poor people in Africa where the population is growing most rapidly are not contributing at all to greenhouse gas emissions," says Lutz.

In 2014, the last year for which comprehensive, comparable figures are available, the World Bank calculates averaged global CO2 emissions amounted to 5 tonnes per capita. For China, it was 7.5, for the US, it was 16.5, for Australia 15.4. For the average member of advanced-economy club the Organisation for Economic Co-operation and Development, that figure was 9.6. The equivalent numbers for the eight developing economies projected to have the largest population increases according to the UN's figures are these: India 1.7 tonnes per capita, Nigeria 0.5, Pakistan 0.9, the DRC 0.1, Ethiopia 0.1, Tanzania 0.2, Indonesia 1.8 and Egypt 2.2. To take, admittedly, the most extreme of those numbers, around 160 citizens of Ethiopia or the DRC have a lower climate impact than one US citizen.

Such simplistic calculations have flaws, of course. Emissions from advanced economies have been declining or flatlining in recent years, whereas those from developing economies are rising as they develop and gain a consumption-hungry middle class. The lifetime difference in emissions between the average person born in India and the US today, for example, may be smaller than the numbers suggest.

Nor do greenhouse gases say everything about our impact on life's support systems – how our growing demand for land, for example, is diminishing biodiversity. But here again, do the sums and work through global supply chains, and the conclusion is that the greater part of that impact is down to the lifestyle of people in high-income economies. If you eat a lot of beef, say, chances are that's directly or indirectly fuelling the destruction of the Amazon rainforest to grow soya as cattle feed. "Unsustainable consumption by the developed region of the world is a major factor in biodiversity decline," says Edu Effiom at the Cross River State Forestry Commission in Calabar, Nigeria.

The looming climate change emergency gives us another reason to hold back from suggesting population control as the solution to the world's woes. Given the impact of having more children extends over generations, having fewer of them won't help us in the decade or so we have to get emissions down and avoid catastrophic global warming. "Population is an important long-term factor in how much warming we eventually experience, but for the climate we live out our lives in, as well as what future generations inherit, it is absolutely critical to stop today's climate pollution," says Nicholas. That suggests the emphasis for people in advanced economies should be rethinking their consumption-fuelled economic models, while helping people elsewhere to develop more sustainably.

The number of children we have is part of that consumption calculation. "Just as people are thinking more about their diet and about flying around the world, the good thing would be for people to appreciate the impacts before they start thinking about reproduction," says Coole.

But there is a limit to how far we can take those discussions. "We have to accept population trends to a certain degree," says Wilmoth. "We have to accept the changes that are going to take place, and the world has to adapt its ways of living. Unless you stop people from having babies entirely, and that would have enormous consequences we don't even want to think about."

Instead, we need to press for more of what works in reducing population growth where population growth is high: education, and support for family planning and gender equality. "It means supporting programmes to give people access to modern contraceptives all round the world," says Wilmoth. Effiom agrees, citing the importance of, for example, stronger measures against polygamy and forced marriage. "It's about enhancing girls' education and empowering them to make choices for themselves," she says. In the long-term, fewer people on the planet can only be good for it. But if that's to be done in a way that respects the rights of all people already on the planet, it can't be a quick fix for the climate crisis. ■

# "THE PROBLEM IS THE PEOPLE WHO ARE SUPER-CONSUMERS"

**Biologist Paul Ehrlich warned about the dangers of environmental collapse fuelled by booming world population over half a century ago. Does he stand by his predictions now?**

## PROFILE
## PAUL EHRLICH

**Paul Ehrlich is a biologist and conservation scientist, and emeritus professor of population studies at Stanford University in California. In 1968, together with his wife Anne, he wrote the influential book *The Population Bomb***

**Since you wrote *The Population Bomb*, the narrative has moved away from overpopulation being a problem. Should it have done?**

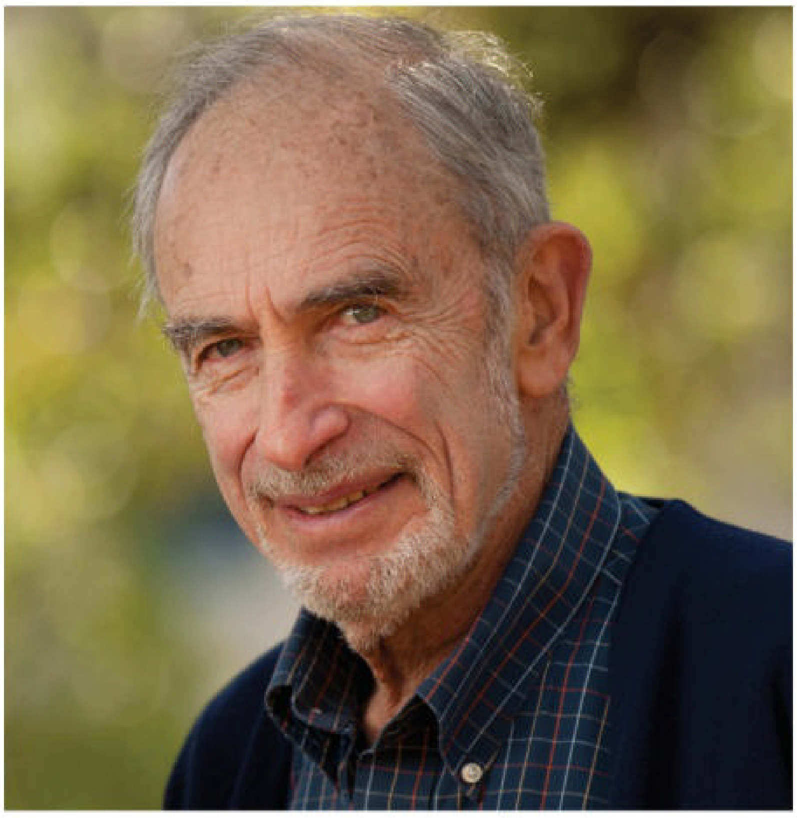
The main problem we have with all our environmental dilemmas is too much consumption. Humans are just using too much of what there is and using more all the time. But to say that the aggregate consumption is just a problem of overconsumption is like saying that the area of a rectangle is it's too wide; it has nothing to do with length. The number of people and how much each one consumes multiply together to give you your aggregate consumption.

**So you stand by your dire predictions?**

It is not the book I would write today. I would put more emphasis on consumption, particularly because we know we can change consumption very fast. You can't change the size of the population humanely with that kind of rapidity. And you don't even want to change it by reducing births too rapidly, because that would have horrendous economic consequences. We should have started reducing births a long time ago and done it gradually.

**So why didn't we?**

I think there are a whole series of factors. One is that we didn't focus enough on giving full rights and



LINDA A. CICERO/STANFORD NEWS SERVICE

opportunities to women. We know that brings down fertility rates, and there isn't a country in the world where women have anything like equal rights and opportunities and pay for the same work as the men. And we're fighting against economic growth mania, which has become built into our culture. Growth is the disease, it's not the cure. As someone once said, anyone who thinks you can have infinite growth on a finite planet is either a madman or an economist.

### How do we solve the problems of overpopulation and overconsumption?

The problem is the people who are super-consumers. There are too many middle-class and rich people who consume too much. And on the other side of the coin is, at least from my ethical standpoint, the whole bunch of people, a couple of billion at least, that need to consume more. You should be taking the best possible care of the people you've already got, and we don't do that.

### How can we take better care of these people?

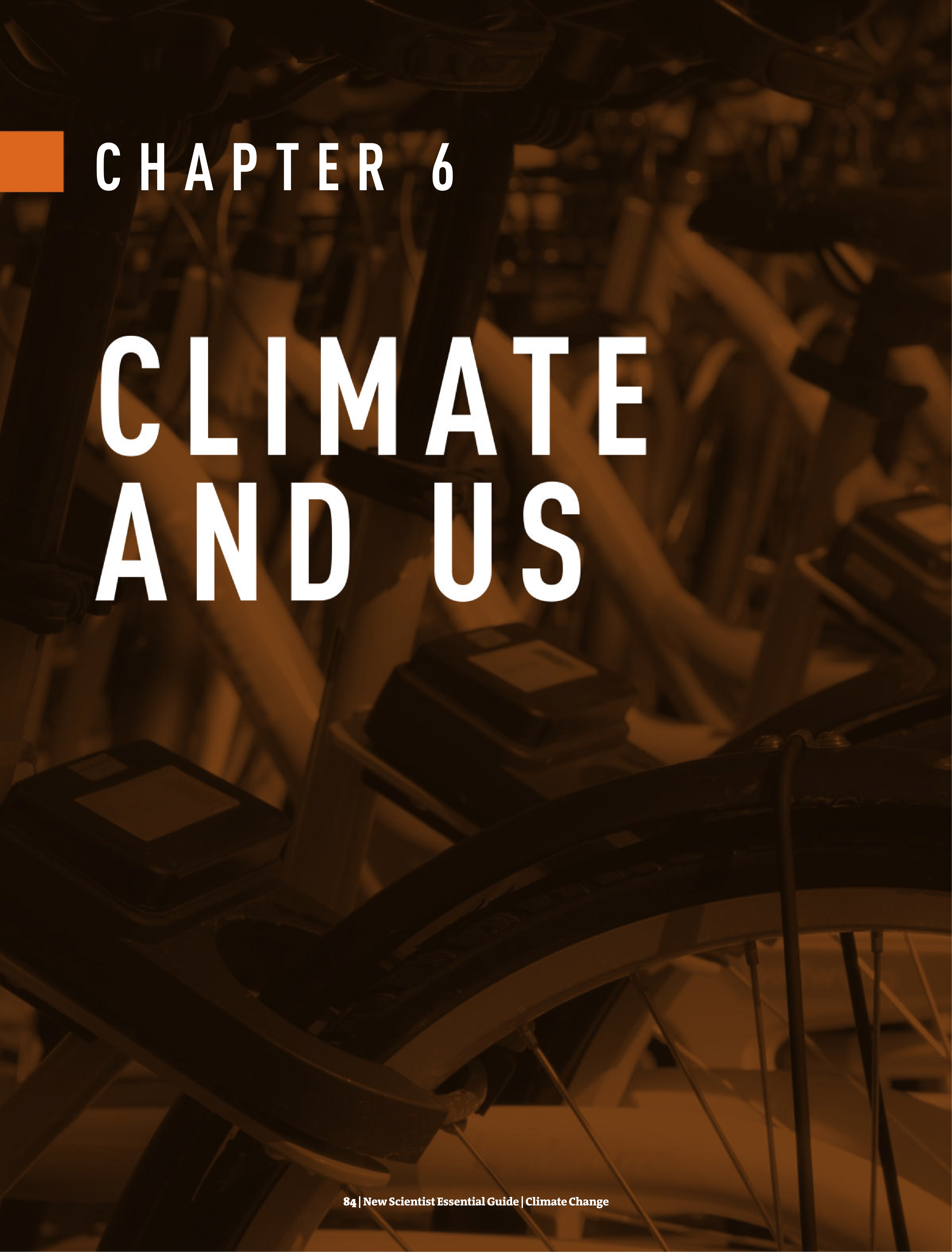
Development is a fine contraceptive. In agricultural economies, where you have mostly subsistence agriculture, children were a net benefit because they were farm labour. Still in parts of Africa, it's the kids that have got to walk to find this ever-scarcer firewood, the ever-scarcer water and so on. Whereas in Britain and the United States, you have to send the kids to university, and it costs you $100,000 or $200,000. So you don't want to have a lot of kids to send to university, so the birth rates drop. Meanwhile give everyone access to modern contraceptives and backup abortion. Nobody I know thinks abortion is a great method of birth-control, but nobody I know either thinks that men should control women's bodies. We should want to make abortion, as I think Bill Clinton said, very accessible and very rare.

### And how should people in higher-income countries be changing their lives?

We should be looking dramatically and rapidly at how to change consumption patterns, because we can do that rapidly. We could get off the fossil fuel standard. What would make me less pessimistic about the future would be some powerful politician getting up and saying, we had a terrible year last year, our GDP went up 1 per cent and we should be trying to shrink it. We have a chance if we really had a way of convincing Brits and Americans that you can actually live without a new cellphone every six months and that you don't have to drive around in SUVs, that you can share vehicles, that you can start tearing down strip malls and tearing up highways and returning areas to natural vegetation while there's still a little time. And perhaps, above all, the rich should be thinking of solving the problems of poor people not with growth, but with redistribution.

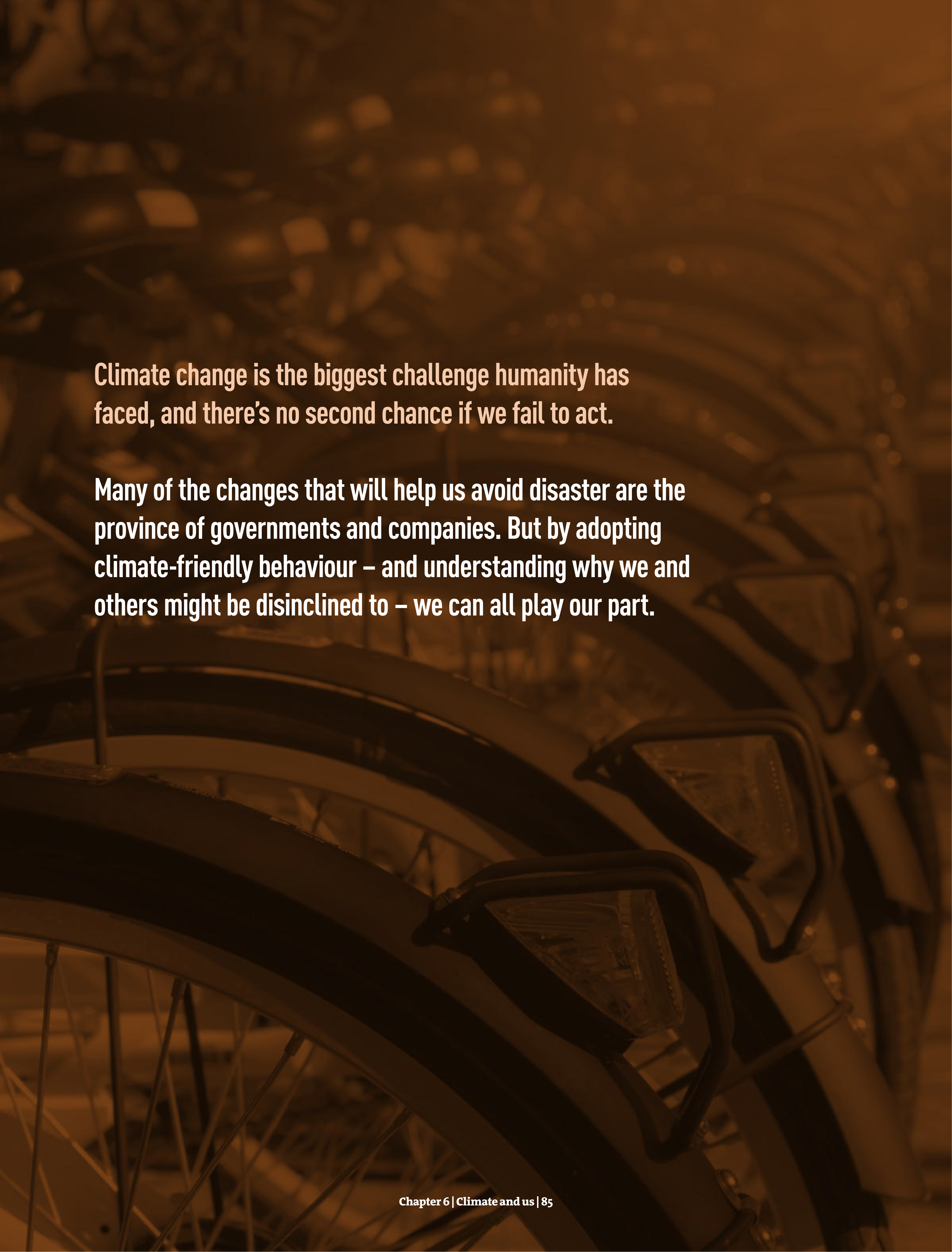
### Are there any grounds for optimism?

What we have in the US, one of the things that Donald Trump did is really stirred up a lot of bright, young kids, and they're the ones who are going to have to solve it. And we know how to harness energy without using fossil fuels. We know how to limit our reproduction safely and carefully. We know how to reduce the chances of pandemics and deal with them when they occur. And Trump gave us a brilliant demonstration of how incompetent leadership can exacerbate large-scale problems, underlining the need for comprehensive planning at the socio-political level and action at all levels. We know how to take good care of the kids we've got at the moment, at least in Britain and the United States. We don't do it, but we know how to do it. And societies, we know from history, can change very, very fast, in either direction. Things can change fast if you have the right incentive. And we certainly have the bright, young people, at least here, to do it, if they want to do it. ∎



## CHAPTER 6

# CLIMATE AND US



Climate change is the biggest challenge humanity has faced, and there's no second chance if we fail to act.

**Many of the changes that will help us avoid disaster are the province of governments and companies. But by adopting climate-friendly behaviour – and understanding why we and others might be disinclined to – we can all play our part.**

# SEVEN THINGS WE CAN ALL DO

**Keeping global warming below 1.5°C doesn't mean everyone has to don a hair shirt. The cumulative effect of small, low-effort actions can be huge. The more each of us does, the closer we get to staving off the worst of climate change.**

RIGHT: ARTMASSA/ISTOCK
PREVIOUS PAGE: FAHRONI/ISTOCK

## THINK ABOUT THE CHILDREN

THE single biggest impact anyone can have on their long-term carbon footprint is to have one fewer child (see graphic, page 88). But this impact is calculated over generations – so won't contribute much to carbon emissions reductions over the next decade where fast action is required to reduce global warming.

←
Chapter 5 has more on population

## DRIVE OFF

Car journeys, especially short ones in cities, account for a disproportionate share of emissions. A third of the carbon dioxide emissions from an average household in the UK, for example, come from road transport. If you can't live car-free, switching to an electric car can largely eliminate the emissions associated with running one. If you cannot go electric, get a smaller, more fuel-efficient car. Avoid diesel because of the air pollution it produces. Or don't own a car: a 2017 study in the Netherlands found that members of a car-sharing scheme drove 15 to 20 per cent fewer kilometres than before they joined, and so emitted between 13 and 18 per cent less $CO_2$.

Leg power can replace many car journeys, too. In London in 2009, for example, journeys to places within walking distance (defined to be up to 2 kilometres) accounted for 11 per cent of the distance travelled in cars, while trips within cycling distance (up to 8 kilometres) accounted for 55 per cent.

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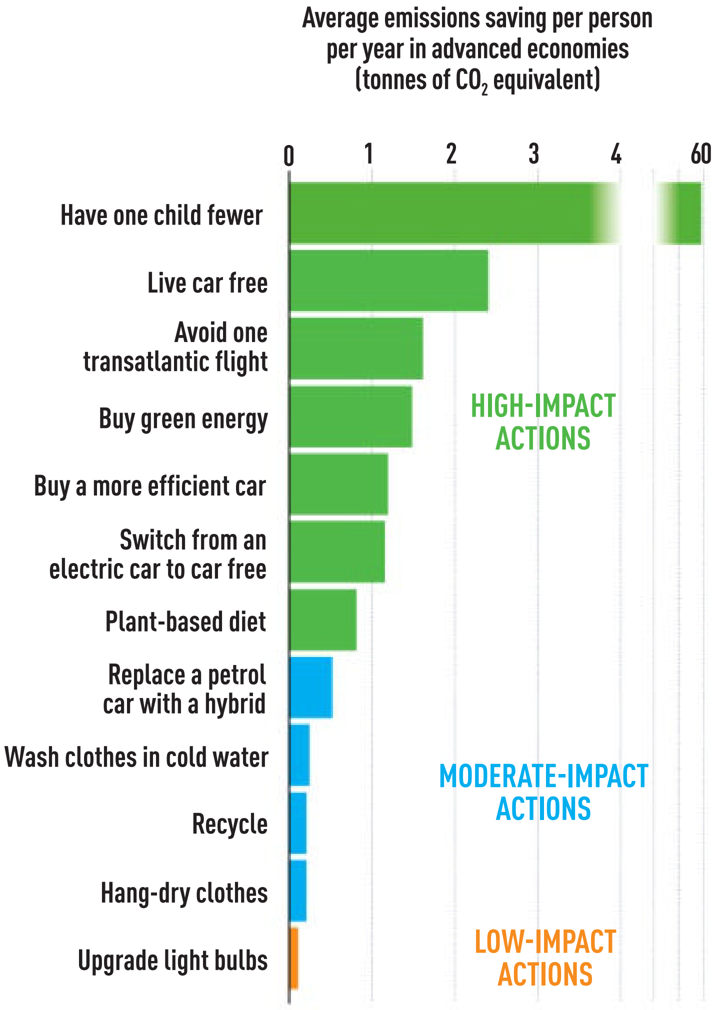
**In high-income economies, having an extra child has a hefty climate footprint, suggesting that the number of children people have should be part of their carbon emissions calculations**



SOURCE: DOI.ORG/GBVRVS

## FLY LESS

Before the covid-19 pandemic, around a tenth of household emissions in the UK were from flying. Frequent flyers can have huge carbon footprints. Flying from London to New York and back produces about a tonne of $CO_2$, while a return economy flight from London to Majorca in Spain – about 2 hours' flying time – emits 490 kilograms, about the same as you would save in a year by going vegetarian or driving 2500 kilometres less.

## VEG OUT

Worldwide, ever more land is being cleared for new farms, which is disastrous for wildlife as well as releasing lots of carbon from, say, deforestation. Shifting to a plant-based diet across the globe could cut carbon emissions from food and agriculture by up to 70 per cent. If nothing else, avoid beef: its carbon footprint is three times that of pork and six times that of chicken.

The second-worst offenders are tropical fruits imported by air, and cheese. Contrary to popular belief, however, what you eat generally matters far more than where it comes from. The emissions per kilogram of red meat and cheese can be around 100 times higher than those for nuts, fruits and vegetables.

## RUN A TIGHT SHIP

According to a US study from 2009, just choosing an energy-efficient model when it comes to replacing a home appliance could reduce your carbon emissions by 1.9 per cent on average. Other simple changes such as lowering the temperature of your hot water and washing machine, using a lower-flow showerhead, not leaving appliances on standby and drying washing on an outdoor line rather than with a tumble dryer can cut a further 2.2 per cent – not huge, but everything counts.

Smart thermostats would make a bigger contribution. A modelling study in Germany in 2017 found that these can reduce a household's emissions by up to 26 per cent, with a bonus reduction in energy bills. And if you are rattling round a big house, consider downsizing. A smaller home can cut your emissions by 27 per cent, according to a UK study in 2016.

## BE A DESK WARRIOR

Offices are a major source of unnecessary emissions. So turn off lights when everyone has left for the day, switch off your workstation when you go home and don't leave phone chargers plugged in when they aren't in use. A UK study from 2017 found that these simple actions can cut office emissions by up to 28 per cent. Even better, don't go into the office if you can get away with it. A US review from 2012 found that homeworkers travel up to 77 per cent fewer kilometres in a vehicle by avoiding a commute. Let some pandemic habits die hard.

## CHANGE INVESTMENTS

One oft-cited claim is that moving your pension funds can have a 27-times greater impact on your carbon footprint than other lifestyle choices. While the precise figure is debatable, there's no doubt that, if you're lucky enough to have investments, whether in a pension or elsewhere, putting pressure to ensure your money is being invested sustainably can have a huge impact, whether directly or through your employer. Get in touch with your elected representatives, too, and press them to press for rules for more transparency about what things investment funds put their money into. ▮

ESSAY

# 33 REASONS WHY WE CAN'T THINK CLEARLY ABOUT CLIMATE CHANGE

**Even people who want to do something about global warming often do nothing, says psychologist Robert Gifford. What are the reasons – and what can we do about them?**

BY NOW, most reasonable people understand that they have been burning too much carbon. Most of these same people are still burning too much carbon. There is a big gap between our views on climate change and our actions to do something about it. Unfortunately, actions are what matter, not sentiments or good intentions.

Most of us have taken some steps in the right direction. However, we continue to produce greenhouse gases. Sometimes, we truly cannot do better. Not everyone can afford to buy solar panels, rural residents cannot commute by subway, and people who live in cold climates cannot go without heating. These are structural barriers, beyond an individual's control.

However, for those not restricted by such barriers, adopting more pro-climate choices and behaviours is quite feasible. Yet, so far, we are not taking enough action to decrease emissions of carbon dioxide and other greenhouse gases. Why is this? What is stopping us from doing at least the things we are capable of?

When I began researching this problem, it quickly became apparent that many of the barriers to action are not structural, but psychological. They are what I call the Dragons of Inaction. In mythology, dragons take on a wide array of forms, and Asian dragons can even be benevolent. However, as a Westerner, I use dragons as a metaphor for these obstacles because Western dragons always seem to be blocking humans from some goal or aspiration. Perhaps another less obvious reason for this choice lies in the word itself: these barriers are a "drag on" progress.

Once one begins looking, a large number of dragons can be found. I have identified 33, classified into seven fearsome families.

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## PROFILE
## ROBERT GIFFORD

Robert Gifford is a psychologist at the University of Victoria, British Columbia, and the author of *Environmental Psychology: Principles and practice*

## Dragon family 1: Limited cognition

Humans are far less rational than once believed – which is also true when it comes to thinking about climate change. This family, the largest, includes 10 species of dragon.

### 1: Ancient brain

Our physical brain hasn't evolved much in 30,000 years. Back then, we were wandering around the savannah, concerned mainly with our immediate kith and kin, proximate dangers and quickly exploitable resources. Although we have learned to think (a bit!) about other people, distant threats and slowly exploitable resources, our ancient brain tends to fall back into the here and now, which is inconsistent with paying much heed to the gradual and often distant impacts of climate change. This makes us slow to act.

### 2: Ignorance

Ignorance is a barrier to action in three ways: not knowing that climate change exists, not knowing what to do about it once you become aware of the problem, and being told wrong information. The first problem is shrinking, although factual knowledge still lags severely: my team tested the climate change knowledge of a representative sample of Canadians. We found that, on average, they could only correctly answer 1.5 out of 6 questions.

Second comes a lack of knowledge about which actions to take, how to undertake those one is aware of, and the relative climate benefits of different actions. We are getting better at understanding the latter, and in broad terms we know what we should be doing. However, much remains to be learned, partly because the answers aren't always universal – a best practice in London may not be a best practice in Vancouver, for example. Also, they aren't always obvious – for instance, lamb raised in New Zealand and eaten in the UK has a smaller carbon footprint than lamb raised and eaten in the UK. And modern products are composed of many ingredients or component parts and have complex life cycles.

Third, ignorance also stems from disciplined and deliberate attempts by groups with a vested interest in the production and use of greenhouse gases to cast doubt on climate science.

### 3: Environmental numbness

This dragon comes in two subspecies. First, every environment is made up of more elements than we can wholly grasp, so we attend to them selectively. Sometimes we attend to salient elements at the expense of less salient but more dangerous ones, which is how accidents happen. Climate change is like that for many: a dangerous phenomenon that isn't salient because it isn't causing any immediate personal difficulties. This makes action unlikely.

The second form occurs at the other end of the stimulus spectrum. When people see the same advert many times, they get used to it and stop paying attention. Similarly, hearing about climate change too often, particularly if the message isn't varied, can lead to message numbness and the attenuation of behaviours that would help ameliorate the problem.

### 4: Uncertainty

Experiments show that uncertainty – both real and perceived – reduces the frequency of pro-environmental behaviour. For example, when asked how many fish they would harvest from a hypothetical ocean, the more uncertain the number of fish left, the more people said they would take. People tend to interpret any sign of uncertainty as sufficient reason to act in self-interest. This happens in the real world too. In its 2007 report, the Intergovernmental Panel on Climate Change expressed its level of confidence in its predictions very carefully, using phrases such as "likely" or "very likely". This led many to interpret the report as indicating a lower likelihood than the IPCC intended. Thus, we are left with a perplexing problem: how to present the likelihood of climate outcomes honestly without promoting underestimates of the problem, which of course help to justify inaction.

### 5: Discounting

One well-known psychological bias is our tendency to undervalue distant and future risks. This is also true of climate change. For example, my colleagues and I found that citizens in 15 of 18 countries believe that environmental conditions are worse in other countries. Although conditions often are objectively worse elsewhere, this tendency occurs even in similar places, such as English villages a few kilometres apart. People also tend to discount environmental risks that will occur in the future. Both types of discounting are a barrier to action against climate change. If conditions are presumed to be worse elsewhere and in the future, people will be less motivated to act.

### 6: Optimism bias

Optimism is generally a healthy, desirable outlook that can produce useful personal outcomes. However, it can be overdone, to the detriment of well-being. For example, people are overly optimistic about their chances of having a happy marriage or avoiding illness. They are also overly optimistic about environmental risks.

### 7: Perceived lack of behavioural control

Because climate change is a diffuse and global problem, many people do nothing because they think that their behaviour has little or no impact on the outcome. Closely related to this is fatalism – the sense that nothing can be done, not only by oneself, but even by collective human action.

### 8: Confirmation bias

We like to be told that we are correct. Therefore, people tend to read and watch media that tells them they are on the right track. Those who have doubts about climate science prefer to read newspapers and watch broadcasts that reinforce their convictions. That, in turn, is a serious barrier to engaging in climate-positive behaviour.

### 9: Time is money

Studies show that when people view the time they have available in monetary terms, they tend to skip acting in environmentally positive ways. Money is the epitome of self-interest, and so when one's time becomes associated with it, the environment suffers.

### 10: Perceived inability

Many pro-climate actions require some extra knowledge, skill or ability. Some people are unable to act because of a physical disability, for example. However, many more are capable of, say, riding a bicycle or changing their diet, but claim to be unable to do so.

## Dragon family 2: Ideologies

This family includes four broad belief systems that inhibit climate-positive behaviour.

### 11: World views

World views are broad swathes of connected attitudes. Some of them include a special place for views on climate change. For example, support for free-enterprise capitalism is especially associated with disbelief in global warming. Capitalism has clearly produced comfortable lifestyles for millions, but some aspects of it, such as a belief in the freedom of the commons – that common resources should be exploitable by anyone – have also led to the devastation of fisheries, forests and landscapes around the world. Having a financial or emotional stake in capitalist organisations isn't compatible with adopting climate-positive behaviours.

### 12: Suprahuman powers

Some people take little or no action because they believe that a religious or secular deity will not forsake them, or will do what it wishes anyway. When researchers at the University of Melbourne in Australia interviewed people living on Tuvalu's main island, Funafuti, which is threatened by rising sea levels, they found that about half weren't worried, maintaining that God wouldn't break the biblical promise never to flood Earth again. More commonly, secular people believe Mother Nature will take a course that we mere mortals cannot influence. Climate inaction follows naturally from these beliefs.

### 13: Technosalvation

Technical innovation has a long and admirable history of improving our standard of living. Clearly, it can be a partner in mitigating climate change: witness the drop in the price of solar panels. However, some go further and believe that technology can solve all the problems associated with climate change. Such overconfidence can serve as another barrier to climate-mitigating behaviour.

### 14: System justification

This is the tendency to defend and justify the status quo. When people have a comfortable lifestyle, the tendency to not rock the boat grows and – more importantly – so does the desire not to let anyone alter the way things are. Climate change will require major adjustments; system justifiers normally won't adopt them, and will argue against them. On a positive note, if mitigation can be portrayed as part of the system, this can change.

## Dragon family 3: Social comparison

Humans are social animals; comparing our own situation to that of others is a deeply ingrained tendency. This dragon family has three species.

### 15: Social comparison

People routinely compare their actions with those of others. When we compare ourselves to someone we admire, we gravitate toward their choices; if that someone happens to harbour anti-climate-science views, we are likely to decide that the climate isn't such a problem.

### 16: Social norms and networks

Norms are what we see as the proper courses of action. They can be a potent positive force for climate action, but they can also be regressive. Social networks create and informally enforce norms. If the network's sentiment is towards doubt, a dragon of inaction naturally reigns. But it works both ways. In one US neighbourhood, for example, dwelling proximity in the network helped explain why 16 per cent of householders installed photovoltaic panels, far higher than the national average of 1 per cent.

### 17: Perceived inequity

Perceived inequity is often heard as a reason for inaction: "Why should I change if they won't change?" Usually other nations or well-known figures are cited as not cooperating, which serves as a convenient justification for one's own inaction. This is backed up by experiments that show when any inequality, real or perceived, exists, cooperation tends to decline.

›

### Dragon family 4: Sunk costs

We like to buy things that will make our lives more comfortable and predictable. Some of these purchases can be climate-positive, but many are not. This dragon family has four species.

### 18: Financial investments

Once we have invested in something, disinvesting in it for climate reasons becomes difficult. The cardinal example here is car ownership. If I have bought a car and am now paying for its insurance and upkeep, why should I sell this cosy portable living room or leave it on the driveway? Similarly, if someone has a financial stake or a job in a fossil fuel industry, believing that burning these fuels damages the environment can lead to cognitive dissonance. It's often easier to reduce this dissonance by changing your belief ("burning these fuels isn't causing a problem") than by changing your behaviour (disposing of the stake).

### 19: Habit

In 1890, pioneering psychologist William James called habit the "enormous flywheel of society" – that is, a powerful force for keeping things regular and ordered. In the context of climate change, habit can lead to the routine, mindless performance of damaging actions. Of course, climate-positive habits are a potential boon.

Habit isn't a glamorous dragon, but it is one of the most important because many repeated actions are highly resistant to permanent change – think of diet and transportation. Some people use the term "behavioural momentum" instead, because it aptly expresses this resistance to change. The use of cars, for example, has a great deal of behavioural momentum, and therefore is very difficult to change.

### 20: Conflicting goals, values and aspirations

Everyone has multiple goals in life, and these aren't all compatible with climate change mitigation. The near-universal aspiration to "get ahead" often means engaging in actions that compete with the goal of reducing climate change, such as buying a larger house, taking exotic holidays or owning a new car.

That climate-related goals frequently take a back seat to others is revealed when people are asked to rank climate change against other problems or concerns: they usually assign it a low importance. Polls carried out by the Pew Research Center think tank reveal that 80 per cent of US respondents say climate change is an "important issue", yet it comes 20th out of 20 when ranked against other issues. Many people favour addressing the economic cost of climate change, as long as it doesn't come out of their own pockets.

### 21: Place attachment

Individuals are more likely to care for places they feel an attachment to. Weak attachment can therefore act as a barrier to climate-positive behaviour. However, so can strong place attachment, for example in Nimbyish opposition to nearby wind farms.

### Dragon family 5: Discredence

When people think ill of others, they are unlikely to believe what they say or take direction from them. These negative views can take a range of forms.

### 22: Mistrust

Trust is essential for healthy relationships. When it is absent between citizens and scientists or government officials, resistance in one form or another follows. There is ample evidence that many people mistrust messages that come from scientists or government officials. When trust sours, the probability of positive behaviour change diminishes.

### 23: Perceived programme inadequacy

Policy-makers have implemented many programmes designed to encourage sustainable or climate-friendly behaviour. Most of these are voluntary, such as a rebate for buying loft insulation or energy-efficient appliances. Thus, people choose whether to accept the offer, and often they decide it isn't good enough for their participation.

### 24: Denial

Uncertainty, mistrust and sunk costs can easily lead to active denial of the problem. This may include denial that climate change is occurring at all or that it is caused by us – something believed by substantial minorities in most countries.

Those holding this view tend to be outspoken. One newspaper reader's comments on an article about research by environmental psychologists is typical of the emotional intensity felt by some deniers: "It figures that a bunch of psychologists need to mess with people's heads to get them to fall in line with this 'eco-friendly' nonsense."

### 25: Reactance

Mistrust and denial lead to what psychologists call reactance, the tendency to struggle against whatever appears to threaten one's freedom. Of course, some circumstances should promote reactance, but climate change isn't one of them. Reactance is especially problematic when it comes to climate because it may promote actions that go beyond inaction into destructive territory.

### Dragon family 6: Perceived risk

Changing one's behaviour is risky. What might those who consider adopting pro-climate behaviour be risking? In this case, there are six dragons of inaction.

#### 26: Functional risk

Will it work? If one purchases, for example, an electric car, it may, as a new technology, have operational problems. The same could be said for many green technologies.

#### 27: Physical risk

Some adaptations may have, or at least be perceived to have, some danger associated with them. Bicycles, for example, produce virtually no greenhouse gases after they are manufactured, but they result in quite a few visits to emergency rooms.

#### 28: Financial risk

Many green solutions require capital outlays or premiums. How long is the payback? If the product becomes a fixed part of a residence, such as solar panels, will I recoup the installation costs or accrue enough energy savings before moving on? Is the premium for that electric car worth it?

#### 29: Social risk

Other people notice many of our choices. This leaves us open to judgement, which could damage our reputation or ego. Will riding a bicycle make me look odd? What about becoming a vegan? Or keeping my old mobile phone?

#### 30: Psychological risk

This risk, which closely follows social risk, is perhaps less likely for most people, but can occur. If we are teased, criticised or even bullied for engaging in climate-positive actions, we risk damage to our self-esteem and self-confidence.

#### 31: Temporal risk

Another risk is the potential that the time I spend planning and adopting a climate-friendly course of action might fail to produce the desired results. Many people spend considerable time trying to decide whether to install solar panels, buy an electric car, become a vegetarian or cycle to a destination. Fear that the choice might not result in the desired benefits can lead to inaction: the time spent planning a change may be wasted.

### Dragon family 7: Limited behaviour

Most of us engage in at least minimal action to help limit the emission of greenhouse gases. However, most of us could do more. This relatively benign dragon of inaction takes two major forms.

#### 32: Tokenism

Some climate-related behaviours are easier to adopt than others, but have little or no impact on greenhouse gas emissions. One example is taking your own shopping bags to the supermarket. However, their ease of adoption means these tend to be chosen over higher-cost but more effective actions, such as commuting by bike or public transport, or switching to a vegetarian or vegan diet. Nevertheless, they might be considered a gateway to better things.

#### 33: The rebound effect

Often, after some positive change is made, the gains are diminished or erased by subsequent actions. For example, people who buy a fuel-efficient car may drive further than when they owned a less efficient one. Like reactance, this dragon may go beyond cancelling out the benefits and produce overall negative consequences.

## SLAYING THE DRAGONS

What can be done in the face of this fearsome army? First, structural barriers should be removed by forces such as legislation and urban renewal, but this isn't likely to be sufficient. You can take some steps, though. Identify your own main dragons, which should help begin the process of slaying them. You can also look for opportunities to join and promote social networks that spread the adoption of climate-positive behaviour.

Other steps need to be taken by researchers from both the social and technical domains, often working together. We need to better understand how people can overcome their barriers. We need to create better measures of the carbon cost associated with various behaviours, so that people know where to put their efforts. We need to better reward those whom I affectionately call the mules: people who are carrying the load for the rest of us by already doing everything within their power. We also need to smile upon the others – I call them honeybees – who engage in climate-positive behaviour for non-climate reasons, such as the cyclist who rides for health or the person who chooses not to have children. Finally, we need to improve understanding of those who oppose policies and technologies for limiting climate change.

The dragons of inaction can be overcome, although it will take time and will never be complete. This must be done expeditiously: we may not have four or five decades to ease our profligate spewing of greenhouse gases and return to a balanced climate. ▮

# “WHAT WE DO REALLY, REALLY, REALLY MATTERS”

**If humanity has any hope of tackling climate change, it needs to take action now, says climate scientist Kimberly Nicholas – making this a nail-biting, but uniquely exciting time to be alive.**

PROFILE
**KIMBERLY NICHOLAS**

Kimberly Nicholas is a climate and sustainability scientist at Lund University in Sweden and the author of *Under the Sky We Make: How to be human in a warming world*

**What’s the meaning of the title *Under the Sky We Make*?**
It came to me when I was travelling overland to a science communication conference in Finland several years ago. I was really struck by what a momentous time we live in. We are the stewards of the very last traces of humanity’s carbon budget. We’re making the sky that we live under, and that our descendants will live under for many generations. We have a lot of agency and power and responsibility. I want us to make the changes we need to make a safe and beautiful sky, not the dangerous one we’re making at the moment.

**You summarise climate change as: “It’s warming. It’s us. We’re sure. It’s bad. We can fix it.” But you also say that science won’t save us. Why would a scientist say that?**
I wanted to convey that science has taken us about as far as it can in the time we have. We know what the problems are, and we have most of the solutions. It worries me that sometimes there’s an excessive faith in science and technology – that we can just switch from fossil fuels to clean energy and carry on exactly as before. That’s not going to be enough. We need social and political and cultural changes as well as implementing scientific solutions.

**The book suggests you already feel a sense of grief over the extent of the climate crisis.**
I’ve been studying climate change since 1997. In that

SIMON CHARLES FLORIAN ROSE

**It's a scientist's duty to point out how we can do better on climate change, says Kimberly Nicholas**

time, it's gone from being something that experts can see in long-term data sets to something we all are living through. In 2017, I was on the phone with my parents evacuating their home during a catastrophic wildfire in California that was made more likely and more devastating by climate change. My stomach was gripped by fear for their lives. That is so different than making calculations and plotting points on a graph.

I also quote my Lund University colleague, the conservation biologist Ola Olsson, saying "Half the wildlife in Africa has died on my watch". Much of what we do as environmental and climate scientists now is about witnessing the demise or death of what we love. That's not what I first thought I was getting into.

### You also express anger, for example at the fossil-fuel industry's denialism. Is that emotional response compatible with the dispassionate role of a scientist?

I absolutely do feel angry at the injustices of climate change: that people who have done the least to cause it suffer the most, and for the injustice across generations. And there is this really well-documented misinformation campaign over decades from the fossil fuel industry. I genuinely do not know how oil executives sleep at night knowing the harm that their products are causing. That is, I think, justifiable and righteous anger.

I think scientists can be human beings with emotions and also do rigorous and fair science. As a sustainability scientist, I must deliver goals that society has set, for example the Paris climate change agreement and the UN Sustainable Development Goals. The governments and the people of the world have said clearly that we want to live in a world where everyone's needs are met and well-being is prioritised, but where we also have thriving land and oceans and a stable climate.

Science tells us equally clearly that we don't live in that world today, and we're not heading for it with the decisions we're making. It's really critical that scientists who have this information speak up, point out this gap and highlight how we can do better and deliver what society has said we want.

### You say that working to undo climate change can be "a crucible to create meaning in our lives". What do you mean by that?

We find things meaningful that are bigger than ourselves, that connect us with others, that are about giving more than taking, that make us part of a story and where our actions are in line with our values. Climate action really gives us the opportunity to put all those things in place. There is no more important task than stabilising the climate and ensuring a good future for all of us alive today and every human who will ever live. It's an opportunity for everyone, way beyond just scientists. ›

**You have given up flying to scientific conferences. Isn't the flexibility that makes such decisions possible a luxury that most people can't afford?**

Definitely. But the people who really need to make lifestyle changes are the people who have that luxury, like me: it's the 10 per cent of the global population who make above about $38,000 per year. Emissions are proportional to income, and we are the real high emitters who need to be changing our behaviour, not the majority who never fly, including half of people in the US and UK.

**Besides travel, there are other areas where we need to prioritise reducing emissions, for example in agriculture and food production. You have a problematic legacy there.**

Globally, almost a quarter of greenhouse gas emissions come from agriculture, and a disproportionately large share of that comes from animal agriculture. My grandfather George helped invent an industrial-style process for making bigger turkeys where you basically feed them highly concentrated corn, soy and wheat, and turn food and clean air into greenhouse gases and an excess of nutrients in the form of animal poop.

A lot of research shows that both for health and for climate reasons, we need to shift to a more plant-based diet. And livestock need to be integrated into a wider system – for example cows grazing on grasslands that benefit from grazing for biodiversity or cultural reasons – rather than feeding animals food that could be going to people.

**How do we protect the interests of people who might have difficulty with the climate transition?**

We do have to pay attention to equity and justice issues, and support the transition for workers in industries like coal mining and aviation that do need to decline to meet climate targets. But there is a smaller number of jobs affected than you might think. In the US, there are fewer people employed in the coal industry now than work at Arby's, a fast-food chain. We can ensure jobs and provide social safety nets and have a stable climate.

**How can we beat apathy about climate change?**

There is research showing that politicians in the UK are well aware of the problem of climate change, but don't feel pressure to act. The drumbeat from citizens needs to be much louder, not just by voting, which is super important, but by supporting and joining and contributing to climate charities and groups working towards the climate transition. Contact your elected officials and talk to them about cars in your city or neighbourhood, or whatever policies are bad for the climate and bad for health and other things. That's a very effective thing to do, and it's rarely used.

**Can we fix things?**

At the moment, we are headed for something like 3°C of warming, which I lose sleep over. We can do it, but it will take a big effort: radical, sweeping changes through society. Fundamentally, nobody knows if we can pull this off or not. But what is humanly possible is what humans make possible. We definitely will not do it if too many people sit on the sidelines. This is an incredibly important, terrifying, nail-biting, but also very exciting time to be alive, because what we do really, really, really matters. ■

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